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Flood Lighting of Statue of Liberty

While this statue has occasionally been lighted in outline by means of incandescent lamps, this lighting was of a temporary nature, and during the past thirty years only the rays from the torch in the hand of the statue could be clearly discerned in the night by those watching on the shore or from ships; but on the evening of December 2, 1916, at a signal given by the President of the United States, the entire statue was instantly bathed in a flood of light which rendered it more conspicuous (by reason of the contrast with the surrounding darkness) than when seen by daylight.

This effect was accomplished by means of 15 batteries of flood-lighting projectors, totaling 246 units, each utilizing a 250-watt Tungsten lamp. Each projector was provided with an individual compensator through which the incoming line voltage of 220 was stepped down to 35 volts for the lamps. The energy supply is transmitted to the Island by submarine cable.

By this means the statue, which stands as the epitome of our national aspirations, is made perpetually visible, glowing with enhanced beauty throughout the night, until with the coming of dawn the man-made illumination is gradually superseded by the light of day. (*General Electric Review*, Jan., 1917.) (*Frontispiece*.)

PRACTICAL ELECTRIC ILLUMINATION

BY

TERRELL CROFT

CONSULTING ELECTRICAL ENGINEER

AUTHOR OF AMERICAN ELECTRICIANS' HANDBOOK; WIRING OF FINISHED BUILDINGS; WIRING FOR LIGHT AND POWER; ELECTRICAL MACHINERY, ETC.

First Edition

McGRAW-HILL BOOK COMPANY, Inc.
239 WEST 39TH STREET. NEW YORK

LONDON: HILL PUBLISHING CO., Ltd.
6 & 8 BOUVERIE ST., E. C.
1917

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PREFACE

Illumination has been defined as "*light utilized for a definite purpose.*" It follows then, that the book *Practical Electric Illumination* is a treatise on the practical utilization of light—which has been generated electrically—for specific uses.

However, before one can utilize most effectively any of the great natural agents, such as heat, light or electricity, he should know something of their principal characteristics. He should, in a general way, understand what they really are, how they act under different conditions and how they may be directed and controlled.

Hence, considerable space in the first sections of this book has been used for a discussion of these things in so far as they concern light. An earnest endeavor has been made to explain in common non-technical English what light really is, how it is probably produced, how it is propagated, how and why it is reflected under certain conditions and how it acts on the human eye thereby enabling us to see things.

Then with the above-outlined groundwork as a basis, in following sections, the quantitative ideas of illumination have been developed. We have tried to explain the real significance of the units used in everyday illumination work. Methods of their application have been illustrated with numerous numerical examples.

Finally the fundamental concepts and the essential units having been explained, the remainder of the book has been devoted to a treatment of actual illumination problems—the lighting of indoor and outdoor areas—and their solutions.

With this, as with the other books which have been prepared by the author, it is our sincere desire to render it of maximum usefulness to the reader. It is the intention to improve the book each time it is revised and to enlarge it as conditions demand. If these things are to be accomplished to the best

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advantage, it is essential that the readers cooperate. This they may do by advising the author of alternations which they feel it would be desirable to make. The future revisions and additions will, to a large extent, be based on the suggestions and criticisms of the readers.

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33 AMHERST AVENUE, UNIVERSITY CITY,
SAINT LOUIS, MISSOURI,
July, 1917.

ACKNOWLEDGMENTS

The author desires to acknowledge the assistance which has been rendered by a number of concerns and individuals in the preparation of this book. Considerable of the material is from articles which originally appeared in certain of the technical periodicals among which are *The Electrical World, The Electrical Review and Western Electrician* and *The Electric Journal.* Among the concerns which cooperated in supplying text data and copy for illustrations are *The General Electric Company, The Westinghouse Elec. & Mfg. Company, The Holophane Company, The X-Ray Reflector Company* and *The I. P. Frink Company.* Considerable of the material is based on publications issued by the *Illuminating Engineering Society.*

Some of the text is taken from Section VI "Illumination" of the author's AMERICAN ELECTRICIANS' HANDBOOK. Messrs. Chas. R. Riker of the Electric Journal and S. Sidney Neu of the Publication Department of the Westinghouse Elec. & Mfg. Company collaborated with the author in the preparation of that Illumination section. Acknowledgment is hereby again accorded for their assistance. A part of the text, particularly that relating to industrial plant illumination, is taken from or based on the writings of Prof. Clewell of the University of Pennsylvania. Prof. H. G. Hake of Washington University, Saint Louis, Missouri, kindly cooperated in reading the final proofs. He located numerous errors and offered a number of suggestions for additions and revisions which were, in so far as feasible, followed.

CONTENTS

PRACTICAL ELECTRIC ILLUMINATION

SECTION 1

FUNDAMENTAL IDEAS OF LIGHT RADIATION

1. Light Is a Form of Energy which radiates from a luminous body. Not all the energy radiated from a luminous body is light, some appearing as heat, but that portion of the energy that affects the nerves of sight and produces the sensation of sight is called light. The radiation proceeds from the source in straight lines (Art. 19) until it is deflected by some intercepting

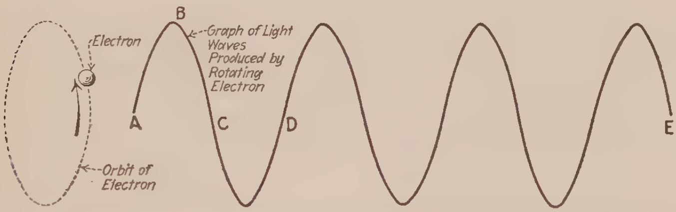

Fig. 1.—Showing diagrammatically one explanation of the production of light waves by revolving electrons (the note under the other similar illustration, Fig. 2, also applies to this).

medium, when it is reflected (Art. 117) refracted (Art. 129), or absorbed (Art. 125). A shadow is caused by some object placed between the source of light and the surface illuminated, which intercepts the light. Light is the immediate external cause of the sensation of sight.

2. As to the Nature of Light, it is due to wave motion or vibratory disturbances in the æther (Art. 3), and it has been further proposed that it is likely that these æther waves are generated by the revolution in their orbits (Figs. 1 and 2) of electrons (Art. 15), which compose the matter of a luminous body. On this basis, the energy which the earth receives

from the sun is in the form of vibrations or wave action in the æther. These vibrations, though we cannot hear them, are the cause of the sensation recognized through the medium of our eyes, which we call light.

3. The Æther is a material or medium which fills all space. This should not be confused with the ether which is the anesthetic which surgeons use. It is not practicable to explain

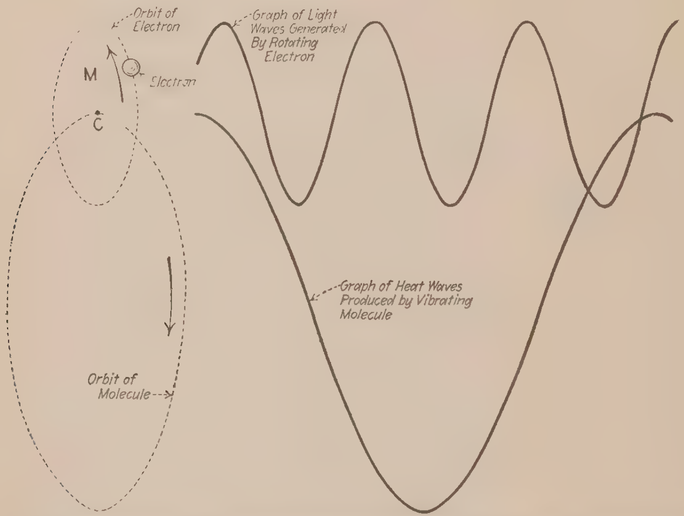

FIG. 2.—Diagram indicating one explanation which has been advanced for light and heat waves generated by the movement of an electron around its orbit in a molecule and by the simultaneous movement of the molecule.

Note.—This diagram is a hypothetical one because it has not been definitely established that the actual situation is as shown above. However, it is probable that this picture is essentially correct.

here why scientists are sure that æther exists and for further information on this subject the reader is referred to the author's PRACTICAL ELECTRICITY. We will here, then, merely state as a fact that it is known that the atoms which, combined into molecules, constitute matter—wood, air, paper, cloth, coal, and all of the things we see and feel around us—are not packed solidly together but that there are enormous (as compared with the diameters of the atoms) spaces between them.

These spaces are not filled with "nothing" as one at first thought might assume, but they are filled with this substance or medium which has been called æther. It is apparent then that "the æther pervades all space."

4. A Mental Picture of the Æther may be constructed in the mind's eye if one considers it as being analogous to a huge mass of jelly in which we are walking around, but of which we do not, unless our attention is especially directed to it, appreciate the existence. This jelly may be thought of as being similar, in certain respects, to the gelatine or jello which is sometimes used as a dessert after a meal. Consider a large hunk of this gelatinous substance. Imagine that a pin has been stuck in one end of the hunk and is oscillated back and forth with the hand. Also assume that another pin has been stuck in the other end of the hunk. It is obvious that the vibrations imparted to the first pin by the hand will be transmitted through the gelatine to the second pin, so that it will then vibrate in approximate synchronism with the first. If now, in the imagination, a block of æther is substituted for the hunk of gelatine, one can then obtain a rough idea of how light waves are transmitted through the æther. Normally, the æther may be assumed to be at rest, but when waves are transmitted through it, it is caused to "vibrate" in somewhat the same way as the hunk of gelatine was caused to vibrate by the motion imparted to it by means of the pin stuck in the end.

5. An Explanation of Wave Motion can probably be best made by means of a simple analogy. The moving waves on the surface of a large body of water, or the ripples on a pond, constitute examples of one sort of wave motion. Consider a specific case:

Explanation.—In Fig. 3 is shown a section of a small pond. How a wave motion may be propagated across the surface of this body of water—and through it—will be shown. If the man suddenly pushes the plunger, P, into the surface of the center of the pond, as shown, at P_{II}, Fig. 4, and then after inserting the plunger he churns it up and down with a regular motion, a train of ripples or little waves will be started across the pond's surface as shown in Fig. 5 and will, after the lapse of a certain period of time, travel in concentric circles to the

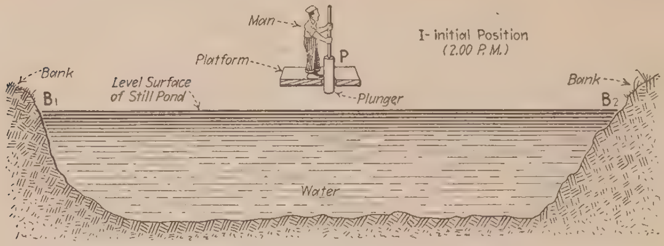

FIG. 3.—Primitive arrangement for illustrating wave propagation.

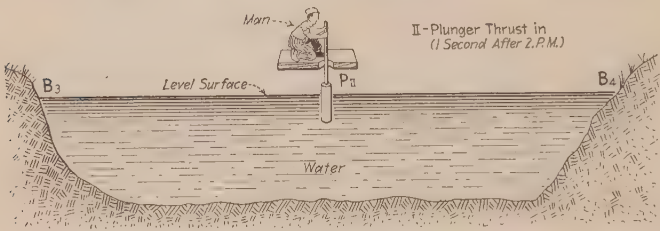

FIG. 4.—Plunger thrust into surface of pond.

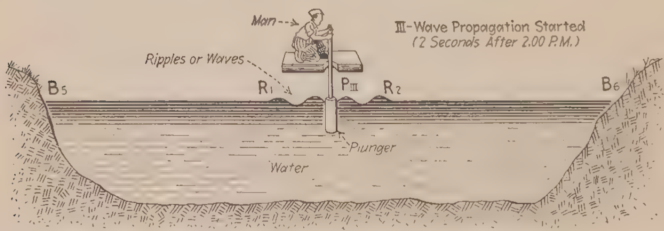

FIG. 5.—Waves or ripples started in their concentric courses across the pond's surface.

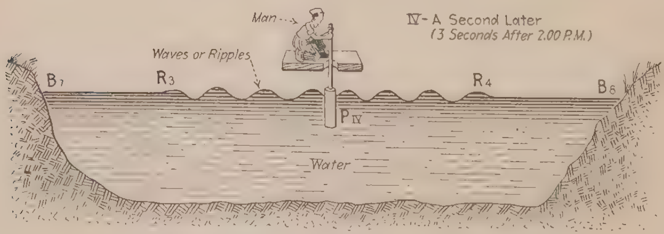

FIG. 6.—Ripples half way across the pond.

shores of the pond as shown in Figs. 6 and 7 which picture conditions at successive instants. It may then be stated that the wave motion due to the insertion of the plunger P_{II} has been transmitted across the surface of the pond as shown in Fig. 7. Probably every reader has at some time or other duplicated the essence of this experiment by throwing a pebble into a body of still water. The pebble caused ripples to radiate in all directions from the location where it entered the liquid. Now, while the observer can see only the ripples—the effects of wave motion on the surface of the pond in Fig. 7—he is justified in assuming that a wave motion is also being propagated under the surface of the water, from X to Y in Fig. 7, that is, the impulse due to the insertion of the plunger was transmitted through the bulk of the liquid as well as along its surface. The wave motion in the æther, to which what we call light is due, is somewhat similar to the wave motion that took place in the body of the water between X and Y in Fig. 7.

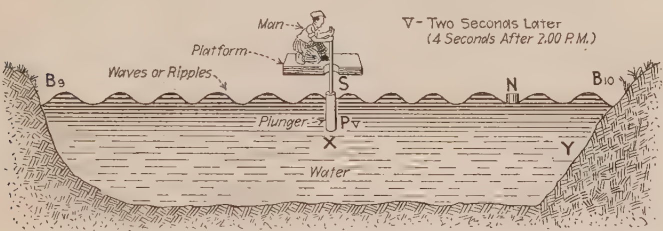

FIG. 7.—Ripples have traveled from center to edges of pond.

6. Light is Due to the Transverse Vibrations in the Æther.—By transverse vibrations are meant those that are at right angles to the line or path of motion.

EXAMPLE.—If a cork, N, Fig. 7, were placed on the surface of the pond it would vibrate up and down vertically as the ripples (wave motion) travelled under it. In other words, the water at or near the surface of this pond was actuated into a state of transverse vibration by the insertion of the plunger, P_V, into it. (Sound waves in the air are due to to-and-fro or "longitudinal" vibrations of the air, not of the æther.)

7. All Æther Waves Travel with the Same Velocity, whether they are light waves, heat waves or the electric waves such as those whereby the signals in wireless telegraphy are propagated. In Art. 8 below it is shown that it has been proven that the speed of propagation of these æther waves is 186,000 miles per sec.

8. The Speed or Velocity of the Propagation of Light, that is, of light waves, is about 186,000 miles per sec., or 11,160,000 miles per min., that is, light (light waves) does not travel instantaneously, although in so far as we are concerned with it in illumination, because the distances involved are so relatively small, it does, for all practical purposes, travel instantaneously. The velocity of light as above stated has been verified by a number of different scientists by several different methods. The first who determined it was Roemer, the Danish astronomer, who in 1675 made the significant observations the gist of which will be described. He was studying the eclipses of Jupiter's moons (Fig. 8). Jupiter has four moons and as they revolve around Jupiter they are eclipsed, that is, they are not visible from the earth, at regular

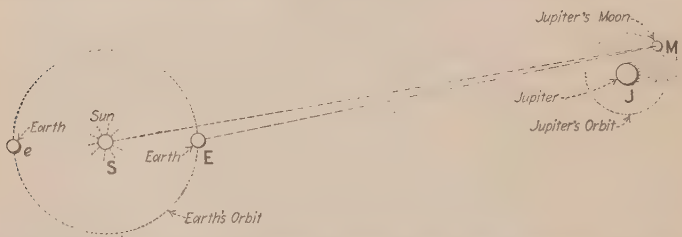

FIG. 8.—Showing how Roemer determined the velocity of light.

intervals. In making his computations, Roemer found that if he computed from his observations the time elapsed between two eclipses, that the eclipse would occur 16 min. and 36 sec. earlier when observed from the earth at position E in its orbit, Fig. 8, than when observed from the earth at position e. Basing his computations on these measurements, he determined that the light would have to have a velocity of about 186,000 miles per sec. to travel the diameter of the earth's orbit in 16 min. and 36 sec.

EXAMPLES.—An express train, if it could travel with the velocity of light, could pass entirely around the earth about seven and one-half times in a second. It requires about 18 hr. for the fastest express trains to travel from New York to Chicago, a distance of a little over 900 miles. If this train could travel with the velocity of light, it would make the run in approximately $\frac{1}{200}$ sec.

NOTE.—It can be shown that *all* æther waves are propagated at the rate of 186,000 miles per sec., hence it follows that heat waves, whereby heat is radiated, are propagated at this rate—as are also light waves and the electric waves whereby wireless telegraphy and telephone signals are transmitted through space.

9. The Meaning of "the Velocity of Light" can probably best be explained by referring again to the pond analogy of Fig. 7. It should be understood that when light is transmitted, nothing tangible is moved along the direction of transmission of the light. Transverse waves are forced to move along the direction of transmission of light but this does not involve the movement of the æther in this direction. For example, in Fig. 7, a wave was propagated along the surface of the pond from S to B_{10}. However, the water on the pond surface was not longitudinally shifted. When, then, a wave motion due to ripples travels across the surface of the pond the water does not travel horizontally, only the ripples travel horizontally. Essentially the same situation holds where light is transmitted.

EXAMPLE.—The velocity of the wave motion propagated across the surface of the pond, Fig. 7, in feet per second would be the distance between S and B_{10}, in feet, divided by the time, in seconds, required for a wave to travel from S to B_{10}. For example, if it took 4 sec. from the instant (Fig. 4) when the plunger was inserted in the water to the instant (Fig. 7) when the first wave reached the shore at B_{10} and if the distance from S to B_{10} was 80 ft., the velocity of wave propagation in this case would then be: $80\ ft. \div 4\ sec. = 20\ ft.\ per\ sec.$

10. The Frequency Is Different for the Different Kinds of Æther Waves.—This in fact is the only essential difference between them because, as stated above, they all travel with the same velocity—186,000 miles per sec.—through free space. By frequency is meant the number of waves that passes a given point in a second. The æther waves of the lowest frequency are the electric waves of wireless telegraphy. Heat waves are of higher frequencies than the electric waves. Light waves are of higher frequencies than are the heat waves. In other words, to affect the nerves of the eye (Art. 23) the æther must be caused to vibrate very rapidly. Again, if the æther vibrates too rapidly it will not produce the sensation of sight. Waves

of frequencies so high that they do not produce the sensation of sight are called ultra-violet waves.

EXAMPLE.—If the plunger of Fig. 7 is churned very rapidly up and down in the surface of the pond, a large number of "high-frequency" ripples or waves will be produced on the surface of the pond. Also if the plunger is churned up and down slowly in the surface of the pond only a few "low-frequency" ripples or waves will be produced on the pond surface. However, regardless of whether the plunger is churned up and down rapidly or slowly, the time required for the propagation of a single wave from its point of origin, P_3, Fig. 5, to the edge of the pond B_{10}, Fig. 7, will be the same. Hence, as above suggested, it may be apparent that the velocity of propagation of æther waves is the same regardless of their frequency.

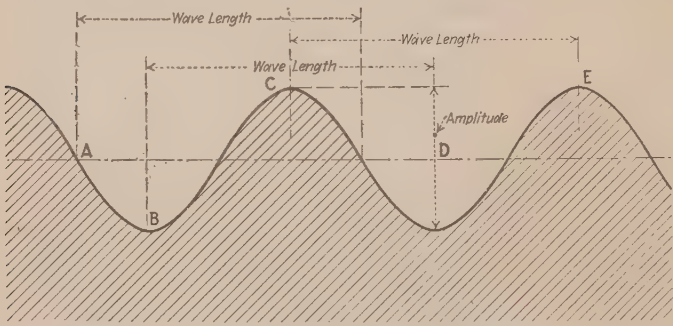

FIG. 9.—Enlarged sectional view of a ripple or train of waves.

11. Wave Length is, Fig. 9, the distance between the crests of two successive waves. Or, it may as properly be taken as the distance between the troughs or between the grooves of two successive waves. While the velocity of propagation of all æther waves in free space is the same, it does not follow that the wave length of any given wave will be the same in some solid substance as in free space. Ordinarily where wave lengths are given in tables and in books it is the wave lengths in free space which are referred to.

EXAMPLE.—The æther waves to which heating effects are due, that is, the radiant heat waves, are a few thousandths of an inch in length. Waves of lengths shorter than $1/30{,}000$ (0.0000333) in. do not react on the nerves of the eye so as to produce the sensation of sight, but longer waves (provided they are not too long) do produce the sensation of sight.

12. The Relation Between Wave Length and Frequency is, for æther waves in free space, a very simple one inasmuch as the velocity of all æther waves in free space is the same. Obviously, every æther wave in free space will have been propagated through a distance of 186,000 miles in 1 sec., hence, if the frequency of a train of æther waves is 2,000 per sec., that is, if 2,000 æther waves are originated per second, one can think of these 2,000 waves as being equally distributed over a length of 186,000 miles. Then in this case, the wave length would be: 186,000 *miles* ÷ 2,000 *waves* = 93 *miles*. Stating this in the form of an equation:

$$\text{(1)} \qquad \textit{wave length in miles} = \frac{186{,}000}{\textit{frequency per sec.}}$$

or,

$$\text{(2)} \qquad \textit{frequency per sec.} = \frac{186{,}000}{\textit{wave length in miles}}$$

The above equations refer specifically to æther wave propagation in free space.

EXAMPLE.—Æther wave lengths which produce the sensation of sight vary in length from about $\frac{1}{32{,}000}$ (0.0000313) in. to $\frac{1}{64{,}000}$ (0.0000156) in. In wireless telegraphy some of the æther waves are several miles in length.

13. The Amplitude of a Wave may (Fig. 9) be taken as the distance between its "crest" and the bottom of its "trough" or "valley."

14. The Sensations of Different Colors Are Produced by æther waves of different wave lengths. What we call white light may be considered as due to the combined effect of waves of all of the lengths which affect our vision. If the waves of certain lengths are screened off so that they cannot enter the eye, then the waves of the lengths that do reach the eye produce the sensation of some certain color.

EXAMPLE.—The number of waves to the inch and their frequencies in billions of cycles per second for the different colors are approximately as follows: red, 340,000 – 400; orange, 370,000 – 440; yellow, 420,000 – 500; green, 480,000 – 570; blue, 510,000 – 600; indigo, 610,000 – 700; violet, 640,000 – 750.

As noted above, the wave length of red light is about $\frac{1}{34{,}000}$ (0.0000294) in., while that of violet is $\frac{1}{64{,}000}$ (0.0000156) in.

15. How Rotating Electrons Are Supposed to Produce Light is illustrated diagrammatically in Figs. 1 and 2. As is explained in the author's Practical Electricity, the atoms of which all matter is composed are supposed to consist of exceedingly small bodies which are called electrons and which rotate in orbits in the atoms. It is now believed that it is these electrons (in revolving around in their orbits billions of times a second) which, in some way or other that is not understood, engage the æther and cause it to vibrate and produce light. The vibration may be produced in somewhat the same way as the block of gelatine described in Art. 4 was caused to vibrate by moving the pin stuck in one end of it back and forth. However, the revolving electrons produce in the æther a sort of rotary transverse vibration (which will be described more minutely in connection with Figs. 10 to 14) and furthermore, the rotating electrons produce, in so far as light waves are concerned, high frequencies (see table of wave lengths above) ranging from possibly 400,000,000,000,000 to 750,000,000,000,000 per sec. The electrons in certain atoms probably rotate very rapidly in small orbits and hence originate ultra-violet wave lengths, of exceedingly great frequency. Other electrons move more slowly in their circular paths and possibly around orbits of greater diameters and thereby generate the wave lengths which are shorter than those of ultra-violet light which cause the sensation of sight. Then again, other electrons are likely revolving around orbits of much greater diameters and are moving still more slowly and thereby produce the relatively long heat wave lengths.

The supposition is that while all of the electrons which compose the atoms of matter are always rotating at high speeds in their orbits the number of revolutions per second that they may ordinarily make is not sufficient to make the æther vibrate rapidly enough to produce what we call light. But when an object becomes heated it is believed that the electrons move more rapidly, thereby generating æther waves of higher frequencies. Then, if for some reason or other, an object becomes heated to such a temperature that it is incandescent,

the electrons move with such rapidity that they do vibrate the æther rapidly enough to produce light.

To Summarize.—The electrons composing all bodies at ordinary temperatures are rotating and thereby generating waves in the æther, but their rotational speed is so slow that light is not produced. If the body is heated, then electrons revolve somewhat more rapidly and produce invisible heat waves in the æther. Finally, if the body is heated to a still higher temperature, so that it gives forth light, some of the electrons revolve still more rapidly and light waves in the æther are the result. We should, then, think of the light which reaches us from the sun as being generated by the revolution of billions and

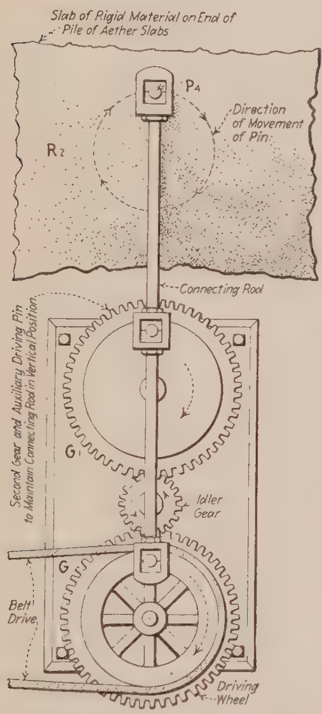

FIG. 10.—Showing how the wave motion might be imparted to the imaginary æther slabs.

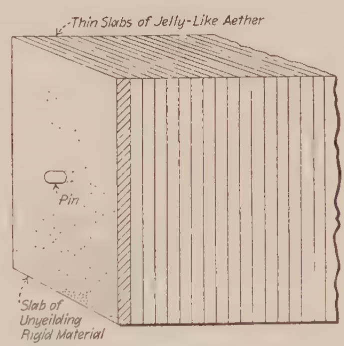

FIG. 11.—A hunk of æther slabs shown in perspective.

billions of these tiny electrons in the sun which is almost 100,000,000 miles away from us. The revolving electrons "stir up" as it were an enormous volume of the æther between the earth and the sun, producing in it these transverse wave motions. Thereby the light waves are propagated to the

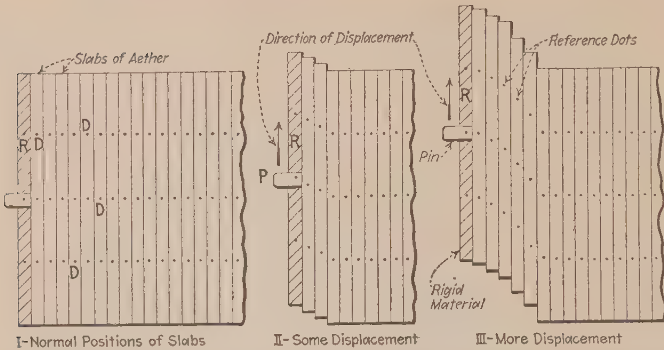

FIG. 12.—Showing normal position and displacement of æther slabs.

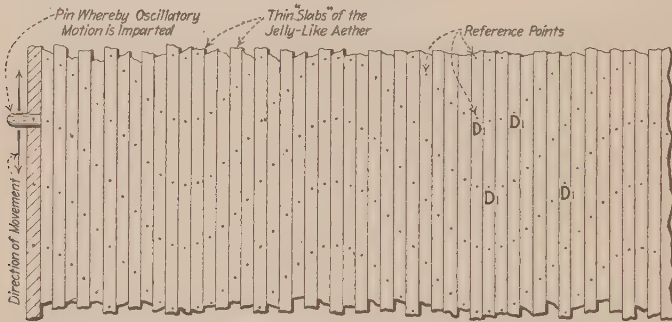

FIG. 13.—A diagram which may assist one in forming a mental picture of how the transverse wave motion which produces light is transmitted through the æther.

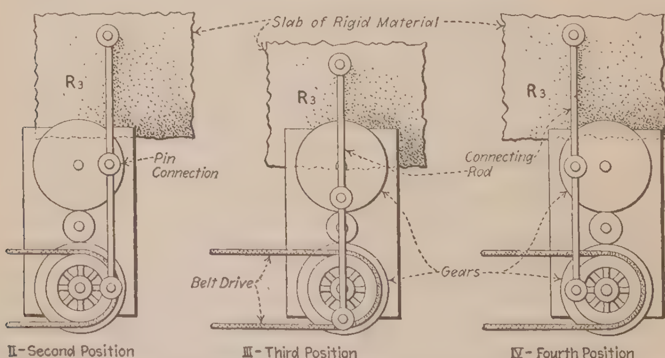

FIG. 14.—Showing different positions as the position of the rigid slab is shifted.

earth. The part that rotating electrons are supposed to play in reflection (Art. 118) of light will be discussed later.

A MECHANICAL ANALOGY INDICATING HOW REVOLVING ELECTRONS MAY GENERATE LIGHT WAVES IN THE ÆTHER will now be given in connection with Figs. 10 to 14. We may, for purposes of explanation, consider that the æther is built up of very thin, jelly-like laminations or slabs (Fig. 11) piled up with the planes of the slabs at right angles to the direction of the transmission of light. Obviously such æther slabs, if they could exist, would be infinitely thin, hence it has been necessary to greatly enlarge them in the accompanying illustrations, which are merely diagrammatic. Consider the side view of a pile of these æther slabs as shown in Fig. 12, *I*. This pile of slabs of *I* is supposed to be inert, that is, not in vibration, the dots *D*, *D*, *D*, etc., plotted vertically along each of the laminations and in horizontal lines across the pile of slabs are merely imaginary reference dots placed so that the eye may readily follow, as the discussion proceeds, the changes in the position of the different laminations. Imagine that a slab of absolutely rigid unyielding material, *R*, is placed at the end of the pile of æther slabs as shown in the illustrations. The pin, *P*, is inserted in *R*, so that it can be moved.

Now imagine that the pin, *P*, is pushed upward as shown at Fig. 12, *II*. The adjacent æther slabs will be displaced out of their normal position about as shown, the phenomenon being almost identical to that which occurs when one moves the top card in an evenly stacked deck of playing cards. The friction or adhesion, or whatever we may choose to call it, between adjacent playing cards transmits some of the shift imparted to the top card to the other cards lying under it. Likewise, with the imaginary æther slabs it can be assumed that the shift imparted by the hand to the rigid plate, *R*, is partially transmitted to these imaginary slabs of æther.

If now, the pin be shifted further, as in Fig. 12, *III*, there will be a further displacement of the adjacent æther slabs about as shown. Also, it is apparent that if the pin, *P*, is moved up and down a train of "ripples" or "waves" will be propagated through the pile of æther slabs. If the pin, *P*, were moved up and down with a continuous and regular motion, a side view of the pile of æther slabs might, at some given instant, appear about as shown in Fig. 13, where the positions of the reference dots D_1, D_1, D_1, etc. (which, when the æther slabs are not in vibration would lie in horizontal lines as shown at Fig. 12, *I*) indicate how the transverse wave motion is being transmitted through this hunk of æther.

If now, the analogy is carried a step farther we can consider that the plate of rigid material on the end of the pile of æther slabs is caused to assume a continuous regular rotary motion by means of the gearing and belt drive shown, then it is obvious that a transverse wave motion would again be transmitted through the pile of æther slabs. However, with

the arrangement of Fig. 10, instead of the slab being caused to vibrate only up and down vertically as was the case with Fig. 12, *III*, it is apparent that the rotary motion, imparted to the pin, P_4, would propagate a wave train through the æther such that the slabs would vibrate regularly not only up and down, but sideways and in fact in every transverse direction. That is, the slabs would vibrate always at right angles to the direction of propagation of the wave train. Fig. 14 shows three different positions, representing different instants, into which the rigid slab, R_3, would be shifted.

Now, we may consider the pin, P_4, as engaging this pile of æther slabs in somewhat the same way as if the electrons revolving in the atoms in the sun engage the volume of æther between the sun and the earth and set up the transverse vibrations in it whereby light is transmitted by the sun to the earth.

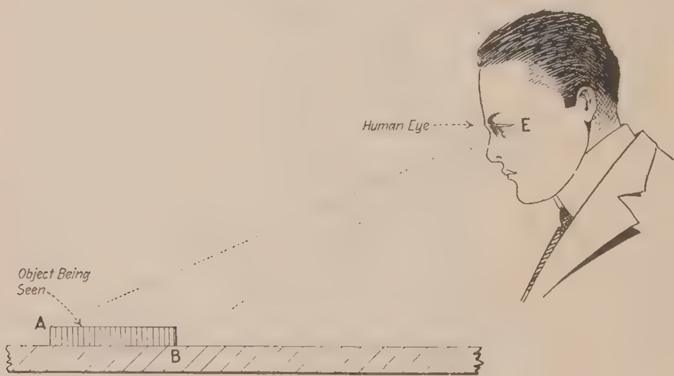

FIG. 15.—How things are seen.

16. What Actually Occurs when We See a Thing is illustrated in a rough way in Fig. 15. If one sees an object, AB, it means that the æther in the cone ABE between the object and the retina of the eye is in transverse vibration, whereby the impression of vision is imparted to the retina. The light which is transmitted from the object, AB, was originated by some luminous or light source (not shown) and transmitted to the eye by reflection. If one looks at a luminous source such as a candle or the sun, then the impression registered on the retina is not a reflected one, but is due solely to the transmission of wave trains through the æther between the eye and the luminous source.

17. Light Waves Transmit Energy as do all other waves, for that matter. A flux of light (Art. 31) can be considered as representing a flow of energy.

NOTE.—It can be shown that light waves exert an actual pressure in the direction of their propagation, just as does the wind. However, this pressure is so small that it is of no practical consequence and is very difficult of measurement unless most refined laboratory methods are used.

18. The Wave Motions Which Produce Light Are Invisible.—This statement may be readily verified by permitting a beam of light to penetrate a dark room through a small hole.

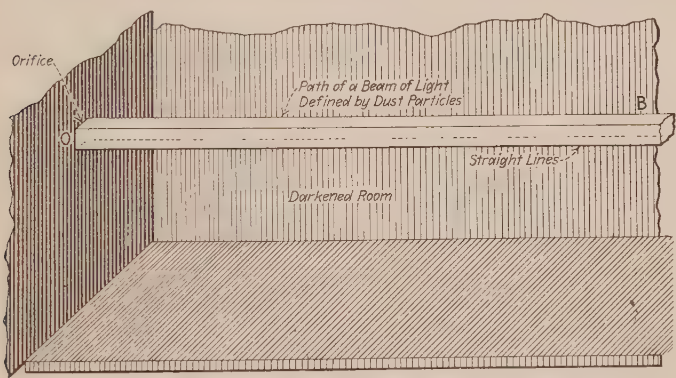

FIG. 16.—Showing how light travels in straight lines.

If the interior of the room is absolutely free from floating dust particles the beam will, if "looked at" from the side, be invisible, but if there are dust particles in the room, then the light reflected from these particles to the eye defines the path of the beam, Fig. 16, of what we call light. It follows then that we are aware of the presence of light only when the columns of vibrating æther which cause it are reflected or projected from some object into the eye.

19. Light Is Propagated in Straight Lines.—This may also be verified (Fig. 16) by noting that the path of the ray of light into a darkened room is absolutely straight. If some small opaque thing be placed in the path of the beam of light between the source and the eye, the source becomes invisible.

20. Sources of Light may be classified into: (1) *luminous bodies* or those which generate and emit light, such as the sun, a candle flame or the filament of an incandescent lamp: and (2) *illuminated bodies* which are visible only because they transmit or reflect (Art. 117) the light, generated by some luminous source, to the eye. Examples of illuminated bodies are the moon, a ceiling which is illuminated by lamps and practically all of the objects that we see around us by virtue of the light generated by the sun or by some artificial light source, which is then transmitted from these things to our eyes.

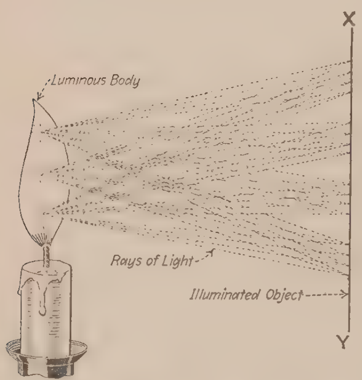

FIG. 17.—Showing how every point in a luminous body emits light in every direction.

21. Every Point in a Luminous Body Emits Light, that is, every point of itself originates light. Thus, as suggested in Fig. 17, any and every point in the flame of a candle, which is a luminous body, emits light. Hence, if a lighted candle is located on the floor in the middle of a dark room, the walls and ceiling and floor (except where the body of the candle casts a shadow) of the room all become illuminated. Furthermore, the candle will be visible to the eye from any part of the room and all of the flame will be visible from any part of the room, which proves that every point in the flame is emitting light in all directions. While in Fig. 17 only three of the luminous point sources of the candle flame are illustrated, it is obvious that the flame actually must consist of an infinite number of such point sources.

NOTE.—On the basis of the electron theory of the generation of light which has been explained in preceding articles, it is apparent that every point in a luminous body must of itself be a source of light because there must be atoms which are composed of rotating electrons at every point in any kind of a body. In a luminous body, some of the component

electrons are rotating with sufficient rapidity to generate the high-frequency light waves.

22. The Mechanism of the Human Eye should be understood if one is to grasp the essentials of scientific illumination. The eye is shown in section in Fig. 18, that is, as it would appear if one side of it were opened in a vertical plane and the enclosing membrane turned back. The eye is really a very delicate and sensitively constructed optical instrument operating on the principle of a photographic camera. Enclosing it is a white outer membrane, S (Fig. 18), which is tough, opaque and firm and which is called the *sclerotic coat*. A part of this membrane, C, which lies directly in the front and which is convex in shape and transparent, is called the *cornea*. Another membrane which lies within the sclerotic coat is called the *choroid coat*. It forms a lining for the inner part of the eye and is covered with a black pigment. The *optic nerve*, N, enters at the rear, where it expands into a network of delicate fibers which are terminated in the *retina*. This retina constitutes the seat of vision. The *iris*, i, is a sort of colored curtain in which is a round hole called the *pupil*. The irises of different eyes are of different colors, that is, one individual may have "brown" eyes, another "blue", etc. The *crystalline lens*, o, is a double convex lens made up of concentric layers resembling those of an onion. This lens weighs about 4 grains and is very transparent. Filling the space between the cornea and the crystalline lens is a crystal-clear fluid which is called the *aqueous humor*. The space within the eye is filled with another jelly-like transparent liquid called the *vitreous humor*.

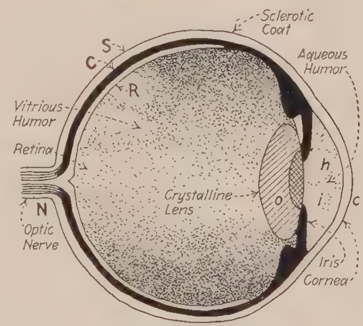

FIG. 18.—The human eye—essential parts shown in section.

23. When an Object Is Seen with the Human Eye, the light from the object (Fig. 19) passes through the cornea, pupil and crystalline lens to the retina in about the same

way as the light which affects the sensitized plate in a photographic camera passes through the lens system. As suggested in Fig. 19, the image of the object, XY, on the retina is inverted, but we do not "see things upside down" because our eyes have become accustomed to automatically correcting the sensation transmitted to the brain so that we actually see things in their correct relation. The image thus formed on the retina is transmitted through the optic nerve to the brain.

24. The Lens of the Eye Automatically Changes in Thickness to Focus, that is, to render distinct, sharp images on the retina when one is looking at things which are at different

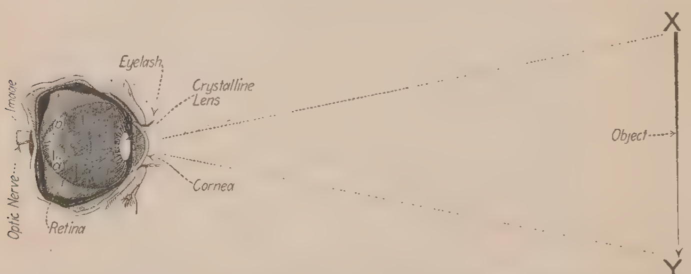

FIG. 19.—Showing how the image of an object which is seen is formed on the retina of the human eye.

distances from the eye. That is, the lens in the eye is self-focusing. In this particular, the eye is materially different from most other optical instruments which, as is well understood, always require manual focusing to insure the clearest and sharpest images. This focusing action is called *accommodation*,* and when the light is dim or bad the focusing muscle vainly "hunts" for some focus which may make objects look clear and gets tired in trying to do it. The muscles which move the eye also get tired in the same way and the result is an eye-strain which causes pain and headache just as any other over-tired muscles of the body may cause an ache.

25. The Iris Serves to Regulate the Amount of Light which Reaches the Retina.*—In very dim light, the iris

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opens, rendering the pupil relatively large in diameter, as shown in Fig. 20, *I*, but when the light is very bright, the iris contracts, decreasing the diameter of the pupil, as shown at *II*, so that an excess of brilliant light which might injure the retina, is excluded. While this protective action of the pupil is very effective, it is by no means complete (see Art. 222 on "Glare"), for the pupil seldom becomes smaller in diameter than shown (relatively) in Fig. 20, *II*, however bright may be the light.

26. The Physiological Features That Must Be Considered in Illumination Problems may then be deduced from a consideration of the preceding description of the mechanism of

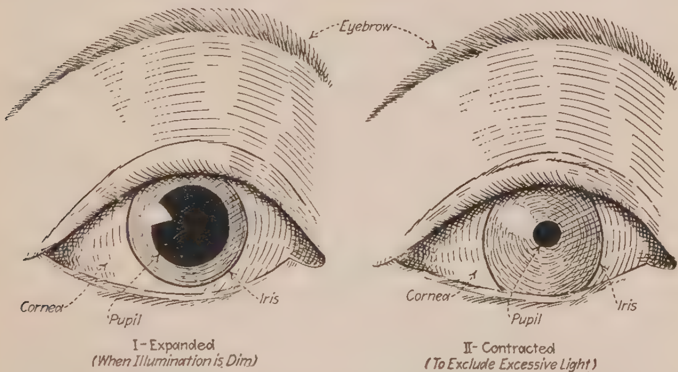


FIG. 20.—Expansion and contraction of the pupil of the eye.

the human eye. Correct illumination enables one to see clearly with minimum tiring of the eyes. To secure this desideratum, all of the following conditions must be satisfied:*

A. WHEN TRYING TO SEE ANY OBJECT, do not allow the light to shine into the eyes and do not face a brightly lighted area. In addition to tiring the retina, the superfluous light causes the pupil to contract so that less light from the illuminated object reaches the retina. An object which would seem well lighted in a room with dark walls and with no light shining in the eyes, will appear poorly lighted in a bright room with light walls or when the light is shining in the eyes—simply because the pupil is smaller. The same sort of reasoning also explains why a higher light intensity is necessary in the daytime than at night. Re-

* PRIMER OF ILLUMINATION, copyright by The Illuminating Engineering Society.

flected light from glossy paper (paper that is termed "coated paper" by the printing trade) produces the same effect as light-colored surroundings. The effect produced by an excessively bright light shining directly into the eyes is termed *glare* (Art. 222).

B. A FLUCTUATING LIGHT CAUSES THE PUPIL TO BE CONSTANTLY CHANGING.—This is very tiring to the muscles which control the iris and if long-continued may even work a permanent injury.

C. THE LENS OF THE EYE IS NOT CORRECTED FOR COLOR VARIATIONS, as is a photographic lens. It cannot, therefore, focus sharply red and blue light for the same object simultaneously, although ordinarily this is not noticed.

As white light is "composed of all colors" (Art. 14), it follows that we can see more clearly, *i.e.*, objects appear sharper and more distinct, by a monochromatic light (light of one color) than by even daylight.

The greenish light from the mercury vapor lamps closely approximates this condition.

D. ILLUMINATION SHOULD BE UNIFORM, otherwise the eye, in continuously attempting to adapt itself to the unequal conditions, becomes tired in the same way as with fluctuating light. See also Art. 222 on "Glare."

27. Sufficient Light.*—There must be sufficient light reflected from objects to enable them to be easily seen. More light must be thrown on dark objects than on light ones.

28. Too Much Light.*—There must not be too much illumination or the brightness of objects will tire and possibly injure the eye as explained under "Glare," Art. 222. This fatigue due to the muscular efforts to contract the iris and partly because of the strong light reaching the sensitive retina.

29. Effect of Daylight on Illumination.—Daylight is so much more intense than artificial illumination that it makes artificial lighting appear dim by contrast. Experiments show that when some daylight is present, from 50 to 100 per cent. greater intensity of illumination is required. This is because the eye gets used to the high intensity of illumination on all objects by daylight, and there are no deep shadows to relieve the monotomy.

* ILLUMINATION PRIMER.

SECTION 2

PRINCIPLES AND UNITS

30. Photometric Units and Abbreviations.*—

	Photometric quantity	Name of unit	Symbols and defining equation	Abbreviation
(*a*)	Luminous flux	Lumen	F	Lumen
(*b*)	Luminous intensity	Candle	I	C.p.
(*c*)	Illumination	Phot., foot-candle	$E = \frac{F}{S}$	Phot. ft.-c.
(*d*)	Exposure	Phot.-second	t	Phot.-sec.
(*e*)	Brightness	Apparent candles per sq. in. Lambert	b $L = \frac{F_r}{S}$	App. c. per sq. in. Lambert
(*f*)	Normal brightness	Candles per sq. in.	$b_0 = \frac{I}{S}$	C. per sq. in.
(*g*)	Specific luminous radiation	Lumens per sq. in.	E'	Lumens per sq. in.
(*h*)	Coefficient of reflection	—	m	

(*i*) Mean spherical candle-power....................s.c.p.
(*j*) Mean lower hemispherical candle-power..........l.c.p.
(*k*) Mean upper hemispherical candle-power..........u.c.p.
(*l*) Mean zonal candle-power.......................z.c.p.
(*m*) 1 lumen is emitted by 0.07958 spherical c.p.
(*n*) 1 spherical candle-power emits 12.57 lumens.
(*o*) 1 lux = 1 lumen incident per square meter = 0.0001 phot. = 0.1 milliphot.

* Abstracted partially from the Rules of the Nomenclature and Standards Committee of the Illuminating Engineering Society. Included by permission.

(p)	1 phot. = 1 lumen incident per sq. cm. = 10,000 lux. = 1,000 milliphot.
(q)	1 milliphot. = 0.001 phot. = 0.929 ft.-c.
(r)	1 foot-candle = 1 lumen incident per square foot = 1.076 milliphot. = 10.76 lux.
(s)	1 Lambert = 1 lumen emitted per square centimeter.*
(t)	1 milli-Lambert = 0.001 Lambert.
(u)	1 lumen, emitted, per square foot* = 1.076 milli-Lambert.
(v)	1 milli-Lambert = 0.929 lumen, emitted, per square foot.*
(w)	1 Lambert = 0.3183 candle per sq. cm. = 2.054 candle sper sq. in.
(x)	1 candle per sq. cm. = 3.1416 Lamberts.
(y)	1 candle per sq. in. = 0.4868 Lamberts = 486.8 milli-Lamberts.

31. Light Flux is the term that will be used frequently and one the significance of which should be thoroughly understood. More information about light flux and how it may be measured and controlled will be given later. For the present, it will be discussed in a general and superficial way only. As defined in dictionaries, the word "flux" means a continuous flowing of something. A "flux of light" may then be regarded as an actual flow of light energy—light waves—from a light-giving or luminous source. As suggested in a preceding paragraph (Art. 8) the velocity of this flow is, as compared with the velocities with which we ordinarily deal, enormous. A light flux is really a volume of quivering æther (Art. 2) which has been forced into transverse vibration by revolving electrons. There is, then, no actual flow of anything material, in the sense in which a liquid flows, in a flux of light. But there is an actual flow of light waves. Hence the student should train himself to think in accordance with this concept. Steinmetz defines thus: "The flux of light is the total *visible* radiation issuing from the illuminant."

32. A Light Flux Can Also Be Thought of as Comprising Many Imaginary Straight-line Rays which issue from the illuminant. This concept is similar to that of a magnetic field which is conveniently thought of as being composed of lines of force which emanate from a magnetic pole. On this basis, the more of these imaginary light rays which impinge

* Perfect diffusion assumed

on an object, the better will that object be illuminated. The fewer the number of these rays which fall on an object, the poorer will it be illuminated. That is, the denser the flux, the greater the illumination. The thinner the flux, the weaker the illumination.

33. A Point Source of Light (Fig. 21) is an imaginary thing which cannot actually exist. But, at the same time, it is an essential element in the development of ideas relating to the art of illumination. A luminous point source—or a point source of light—is one which is infinitely small (a mere

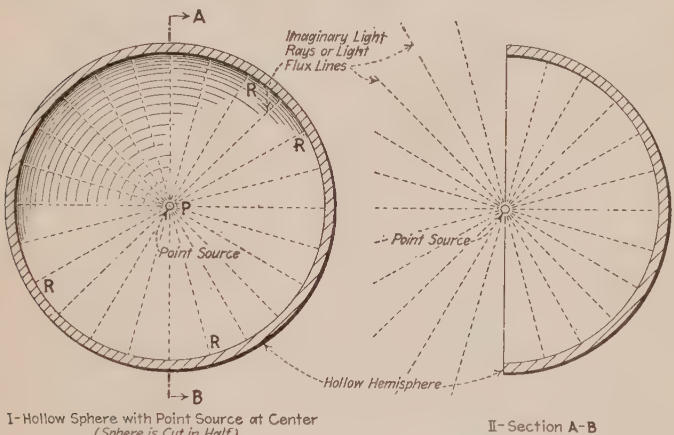


FIG. 21.—Diagrammatically illustrating a point source.

mathematical point in space) and from which light is sent out or radiated and equally in all directions.

NOTE.—Although a point source is a mere theoretical concept, in practice an actual light source may often (under certain conditions to be defined later, Art. 37) without prohibitive error, be considered as a point source, if the distance from the actual source to the location at which the light is measured is ten to fifteen times as great as the apparent size of the light source.

EXAMPLE.—In Fig. 21 a very small luminous sphere, P, may be taken representing a point source of light or of luminous flux. The sphere has been cut in half so that one may look inside of it. P has, in the picture, been made of exaggerated size so that it can be seen easily. Now, if a point source were, as shown, placed at the center of a hollow sphere, it

would, because of its properties as defined above (Art. 33) radiate light equally in all directions. This is shown diagrammatically in Fig. 21 by the imaginary flux lines which are supposed to issue, equidistantly spaced, in all directions from *P*. It follows then, that every point on the interior surface of the hollow sphere would be equally illuminated—because the light waves issue from *P* radially and equally in all directions.

34. A Standard Light Source or Luminous Source of some sort, against which other luminous sources may be compared, is, obviously, necessary in the development of ideas relating to illumination. It early became evident to the pioneers in the art of illumination that some sort of a standard of comparison or reference, whereby one light source could be qualitatively compared against another, was necessary. During these periods of many years ago, tallow or sperm candles were used quite generally for illumination. The candles were, broadly speaking, always of about the same diameter, made of about the same materials, and in an approximate way, developed about the same candle-power.* The simplest and most available standard light source at that time was, then, a candle. Hence, the so-called "standard candle" which was described as a sperm candle weighing $\frac{1}{6}$ lb. and burning 120 grains of its material per hour, was adopted as a standard light source and was so used for a number of years. However, it is apparent that a sperm candle is not, inherently, a very accurate or a very reliable standard.

35. Tallow or Sperm Candles Are Seldom, if Ever, Used at This Time as Standard Light Sources because, as will be shown later, other more convenient and inherently more accurate standard light sources have been developed. However, the term "candle" has (Art. 47) been adopted as the name for the unit of light-producing power or luminous intensity of light sources. For the present, it is sufficient to note that reasonably accurate and reliable standard light sources (Art. 48) have been developed, and that now the term "luminous intensity of 1 candle" has a perfectly specific and well-defined meaning.

NOTE.—A luminous point source of a light-giving power or luminous intensity of 1 candle, rated in accordance with our present relatively

* See PHOTOMETRICAL MEASUREMENTS by W. M. Stine.

accurate standards, would be, approximately, of the same light-producing power as a 1-c.p. source rated on the basis of the old sperm-candle standard described above. It should be particularly noted, however, that the "candle-power" or luminous intensity of an actual light source does not have a specific meaning (Art. 53) unless the precise direction in which the power is measured is specified.

It should also be noted here that, as discussed more fully further on (Art. 41), the terms candle-power or luminous intensity may be properly applied only to a true theoretical point source of light. There is, strictly speaking, no such thing as the candle-power of an actual light source such as a tallow candle or an incandescent lamp. We may, however, properly refer to the "apparent" candle-power (Art. 52) of an actual light source. When, then, one refers to the candle-power of an incandescent lamp or an arc lamp, he really means the apparent candle-power of that source because neither an incandescent lamp nor an arc lamp is a true point source.

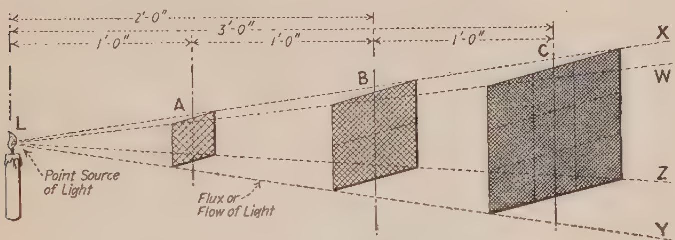


FIG. 22.—The radiation of light.

36. Density of Illumination Varies Inversely as the Square of the Distance from a Point Source.—This, which is sometimes called the *inverse square law*, is an important fundamental fact which can be verified experimentally quite readily. We know by common observation that any object—a printed page, for example—will be as well illuminated by a common tallow candle flame if it is held reasonably close to the candle flame as it will be by a most-powerful arc lamp if it is held a considerable distance from the lamp. Why the density of illumination must vary as the square of the distance from the source can be best understood from a consideration of specific examples.

EXAMPLE.—In Fig. 22, it is evident, because of the construction of the picture that three sheets of cardboard, *A*, *B* and *C*, of exactly the

three different sizes shown, held successively at locations 1 ft., 2 ft. and 3 ft. distant from the point source L would intercept the same total amount of light flux the flux in the pyramid $LWXYZ$. Note that B has four times the area of A and that C has nine times the area of A.

Now, although the same total light flux would impinge on A as on B, it is evident from the picture that the flux on B "is spread out" over four times the area that it covers at A. That is, the flux on the surface at A is four times as dense as the flux on the surface at B. In other words, the flux density at A is four times that at B. This means that the illumination of A will be four times that of B because the denser the flux, the greater the illumination. That is, B is two times as far away from L as is A, and the illumination or flux density on B is one-fourth that of A. Obviously, the illumination must, then, vary inversely as the square of the distance from the point source L, because the square of 2 is 4 and the inverse of 4 is $\frac{1}{4}$. Again, C is three times as far away from L as is A, but it has nine times the area, hence the illumination of C is one-ninth that of A. That is, three times the distance, one-ninth the illumination.

Example.—The illumination developed on the surrounding objects by the beam from the lighted headlight (which has a reflector which diffuses its light through wide angles) of a locomotive, *which is approaching at a uniform speed*, increases very slightly when the locomotive is far away, but as it draws nearer, the illumination increases very rapidly. This situation constitutes an approximate qualitative demonstration of the truth of the inverse square law.

37. The Limitations of the Inverse Square Law may be stated thus: Although the inverse square law, as stated above, applies with absolute accuracy only to the light emitted from a source so small that it may be considered as a point source, in practice results are, as suggested in Art. 33, sufficiently accurate if the distance from the source to the point at which the light is measured is 10 to 15 times as great as the apparent size of the light source.

38. The Density of Illumination Does not Always Vary Inversely as the Square of the Distance from the Source.—The inverse square law holds strictly only for a point source. It is closely, though not exactly, true for a source which approximates a point source, but with certain sorts of light sources it may not hold at all. Consider Fig. 23, in which the light from a light source is directed by a theoretically perfect parabolic reflector. A reflector of this sort has, when the light source is properly located within it, the property of projecting all of the light in perfectly parallel rays or in a beam.

With a theoretically perfect parabolic reflector and with the light projected through an absolutely transparent medium, the flux of quantity of light at any location along the beam, as for instance at A in Fig. 23, would be the same as at any other location along the beam, as at B. Hence the density of illumination would be the same on a sheet of paper placed at A as on a sheet at B. Parabolic reflectors that are used for automobile headlights and sometimes for searchlights give results which approximate this condition.

NOTE.—Obviously, a perfectly parabolic reflector and a perfectly transparent medium are impossible. The illumination—flux density—due to the beam of light projected by a parabolic reflector does, in practice, actually diminish as the distance from the lamp increases. This is due to the imperfections of the reflector, to the dirt and smoke in the

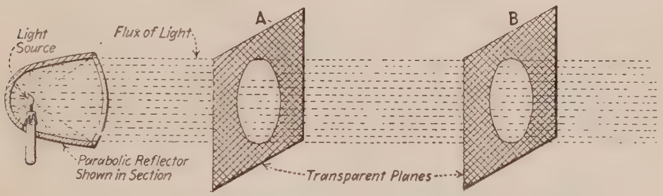


FIG. 23.—Light projected by a parabolic reflector.

air and to the reflection (Art. 117) and absorption (Art. 125) caused by the particles in suspension in the air. The above-outlined property of a parabolic reflector is noted merely to emphasize the fact that the amount of volume of light produced by a source is a perfectly definite quantity. The beam of light projected, from a point source properly located in a perfect parabolic reflector through a perfectly transparent medium, would extend out to an infinite distance and the density of the illumination at any point along the beam would be the same.

39. There Are Three Fundamental Concepts on Which the Art of Illumination Is Based.—They are: (1) *Luminous intensity* of a point source of light measured in candles, Art. 35. (2) *Illumination*, or luminous flux density, measured in foot-candles. (3) *Luminous flux*, measured in lumens. The significance of these three concepts and of the corresponding units in which they are measured or evaluated in practice must be well understood if one is to obtain good working ideas

of the principles of illumination. Each of these three quantities and the units in which it is measured will be discussed in following articles.

40. The Luminous Intensity or Candle-power of a Light Source is a measure of the light-producing power of that source. The term "candle-power" is the older one and has, in a measure, been superseded by luminous intensity. However, (Art. 43) "candle-power" is a perfectly proper term. If we think of a light flux as comprising a bundle of rays, then luminous intensity is the density of the light flux at the surface of the point source illuminant. The luminous intensity or candle-power of a light-giving point source is then a measure of the ability of that source to agitate the æther into transverse vibrations and thereby produce the phenomenon which we call light. Luminous intensity is measured in a unit, called the candle, which is described below.

41. There Are Two Facts Which Should Always Be Remembered about Luminous Intensity.—*The first is*, that, strictly speaking, it can relate only to a light-producing source of some sort. *The second is*, that, strictly speaking, it can relate only to a theoretical point source of light. It follows, then, that it is not entirely accurate to refer to the luminous intensity of any light source unless it is a point source. However, we may refer to the *apparent luminous intensity* of some actual light source, if the location where the measurement is being taken is so far distant from the source (Art. 52) that the source may be, for all practical purposes, regarded as a point source. In any case: "Luminous intensity refers only to a single beam, to the physiological effect at a point."

42. The "Candle" Is the Unit of Luminous Intensity.—An apparent luminous intensity or light-giving power of 1 candle may be defined as the light-giving power of a light source (made and used in accordance with certain definite specifications) which has been adopted as a standard unit light source by the U. S. Bureau of Standards at Washington (Art. 47). As suggested above (Art. 34), an ordinary sperm candle burning 120 grains per hr. develops an apparent luminous intensity of approximately 1 candle, in a horizontal

direction. As defined in A. I. E. E. STANDARDIZATION RULE 855. "The candle is the unit of luminous intensity maintained by the national laboratories of France, Great Britain and the United States."

43. Candle-power* is luminous intensity expressed in candles.

44. The Practical Significance of Luminous Intensity is, probably, the thing that is of real interest to the reader, rather than the basic theoretical features outlined above. If luminous intensity in candles could be measured only for theoretical point sources the whole concept would be of no practical value, because, as outlined in Art. 33, a true point source can exist only in the imagination. It will, then, be well to examine some of the practical considerations affecting the actual situation:

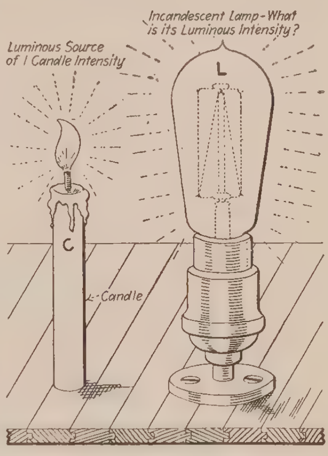


FIG. 24.—A "comparison" of two light sources.

EXPLANATION.—First of all, it should be noted that it is not feasible to directly compare the apparent luminous intensity of two light sources. Thus (Fig. 24) if it is known that the lighted candle, C, has an apparent luminous intensity of 1 candle in the horizontal direction, one could not determine by looking at the candle and the lighted incandescent lamp, L, placed side by side, the apparent luminous intensity in candles of the lighted incandescent lamp. One could not tell, by mere inspection, how many times greater the apparent intensity of L is than that of C. But the apparent intensities in certain directions of two light sources may be compared quantitatively by an indirect method by comparing the illumination effects which each produces, as will now be shown:

THE PRINCIPLE OF THE PHOTOMETER, which is an instrument for comparing the apparent intensity of one light source with that of another, which is taken as a standard, will now be discussed. Assume that it might be possible to place a true theoretical point source (Art. 33) of light of unit—1 candle—intensity in the location L_1, Fig. 25. It would

* A. I. E. E. STANDARDIZATION RULE 856.

illuminate the face of the paper screen, S_1, nearest it to a certain density. Now, if some other actual light source, L_2, for example, were placed at L_2, and it illuminated the face of L_1 nearest it to the same density of illumination as that produced by L_1 on its face of S_1, it is almost obvious, assuming distance L_1S_1 equals distance L_2S_1, that L_2 has an apparent luminous intensity in the horizontal direction of 1 candle.

One can determine with fair accuracy when the illuminations on the two sides of screen S_2 are of equal density, if the screen is prepared about as follows: On the center of the piece of white unglazed paper, drop some melted paraffin forming a spot about 1¼ in. in diameter. Then, after it has cooled, scrape off the surplus and press down, with a sheet of clean paper between them, a hot sad iron over the spot to soak the paraffin into the paper. Then this screen should be supported on a movable block about as shown in Fig. 25 and the whole arrangement mounted on a suitable table. The center of the paraffin circle in the screen and the centers of the two light sources, L_1 and L_2, should be in the same straight

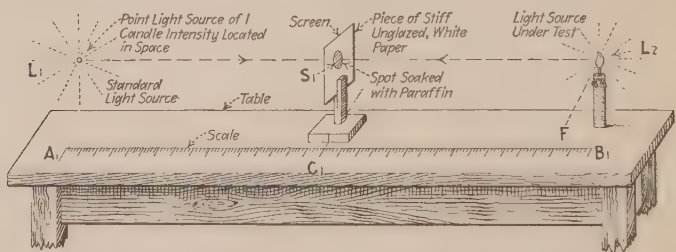


FIG. 25.—A unit point source used as a standard of comparison.

line. The centers of all three should be at the same vertical distance from the top of the table. With both light sources, L_1 and L_2, projecting light on opposite faces of the screen the illumination on its two opposite faces will be of equal density when the paraffin spot is either invisible or the least conspicuous—when it is viewed from a location in line with L_1S_1 and L_2. A grease spot on the sheet of paper may be used instead of a paraffin spot.

L_1 is (because it has been so selected) a true point light source of 1 candle intensity. This means that it has a light-producing power of "1 c.p." in all directions. As suggested in connection with Fig. 21, a point source, by definition, emits light equally in all directions, hence L_1 can be rotated or turned into any position—its center always remaining at the same point—without altering at all the illumination produced by it on the side of S_1 nearest it.

But L_2, Fig. 25, not being a point source, does not emit light equally in all directions. For example, it can be shown by test that less light is emitted in the direction L_2F than in the direction L_2S_1. Furthermore,

there is no light at all emitted along a line drawn vertically downward from L_2 because the wick and the body of the candle prevent the projection of any light vertically downward. Note this then particularly, that while *the actual luminous intensity in candles of a point source is the same in all directions, the apparent luminous intensity in candles of actual sources of light may not be, and in fact never is, the same in all directions.*

The apparent luminous intensity or light-producing power of L_2 is, so it has been determined as above, by comparison with a standard source L_1, 1 candle *in the horizontal direction* L_2S_1. But its apparent intensity or light-producing power in other directions may be more or less than 1 candle. So it is evident that a statement of the apparent intensity or apparent candle-power of any actual light source is meaningless unless it is specified either directly or indirectly in what direction the apparent luminous intensity was measured. "Luminous intensity can be applied only as referred to a point, to a single ray of infinite diameter and is a measure of the ability of a point source to give forth light."

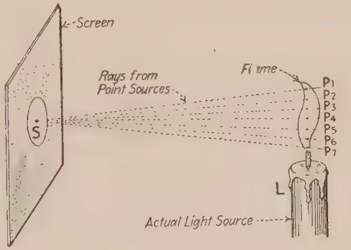


FIG. 26.—Showing how the illumination at the point S may be due to the combined effects of many point sources.

Although luminous intensity relates only to a point source, the luminous effect of an actual source of light in a certain direction may be regarded as due to the combined effects of a number of point sources within

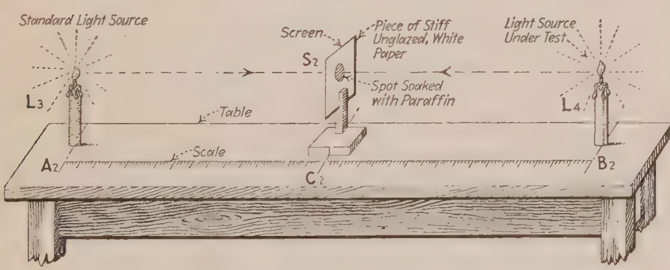


FIG. 27.—Illustrating the principle of the photometer.

the actual light source. For example, the illumination at S, Fig. 26, may be regarded as due to the effects of the combined sources P_1 to P_7 of the actual light source L. That is, it may be stated that the apparent luminous intensity of L in the direction P_4S is due to the seven point sources shown in L—and to many more that are not shown. If then, it is determined by test as in Fig. 25, that L_2 has an apparent luminous intensity in the horizontal direction, L_1S_1, of 1 candle, this actual light

source (L_2) can now be used as a secondary standard or reference source and utilized in Fig. 27 where it will be called L_3. If now, another actual light source is arranged at B_2 as shown and it is found that both sides of S_2 are equally illuminated (when S_2 is exactly midway between L_3 and L_4, and L_3S_2 and L_4 are all in the same horizontal straight line), then it is evident that this new light source, L_4, is also one of a luminous intensity of 1 candle in a horizontal direction.

Furthermore, with this same arrangement, the apparent luminous intensity, in some certain direction, of a light source more powerful than our now-standard 1-candle source, L_2, may be determined. Assume that it is desired to determine the luminous intensity in the horizontal direction of a lighted incandescent lamp which is standing vertically. The apparatus is arranged as suggested in Fig. 28. The calibrated source, L_2, is used as a standard and is, in this illustration, designated as L_5. The screen, S_3, is shifted longitudinally in line with L_5 and L_6 until a position

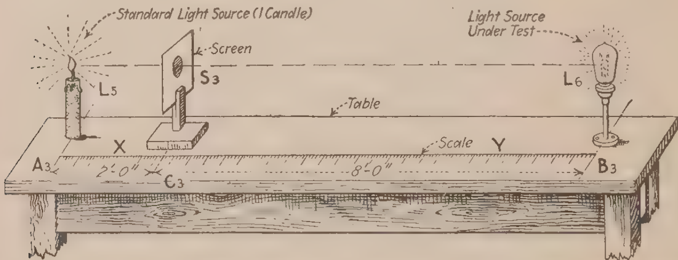


FIG. 28.—Comparing the luminous intensities of a "Standard" candle and an incandescent lamp.

is found at which both faces on S_3 are illuminated equally. Now it has been shown (Art. 38) that the density of illumination on an object varies inversely as the square of the distance from the source of light. Hence, if both faces of S_3 are equally illuminated (that is, if the density of illumination on S_3 due to L_5 is just equal to that on S_3 due to L_6) the apparent luminous intensities of L_5 and L_6 in the horizontal direction must vary as the squares of the distances of L_5, 2 ft., and L_6, 8 ft., from S. Now, $2^2 = 4$ and $8^2 = 64$. Then: $64 \div 4 = 16$. Then, L_6 must have 16 times the apparent luminous intensity or light-producing power that L_5 has—in the horizontal direction. Since L_5 is of 1 candle apparent luminous intensity in the horizontal direction, the apparent luminous intensity of L_6 must then be 16 candles in the horizontal direction.

45. Luminous Intensity Is the Amount of Disturbance Imparted to the Æther by the Light Source.*—It is proportional to the square of the amplitude (Art. 13) of the vibra-

* See Steele's PHYSICS.

tion of the æther particles. That is, as the luminous intensity at the source increases, the amplitude there increases; as the luminous intensity decreases, the amplitude there also decreases. The amplitude of vibration varies inversely as the square of the distance from the source, which means that the density of illumination (Art. 72) varies inversely as the square of the distance from the source.

46. In the Practical Determination of the Luminous Intensity of an illuminant, to determine its candle-power or intensity in candles, the illuminant is compared with a standard (Art. 47) maintained by the U. S. Bureau of Standards at Washington, D. C., or with a well-seasoned incandescent lamp (a secondary or working standard) which has been calibrated by direct or indirect comparison with the standard maintained at Washington.

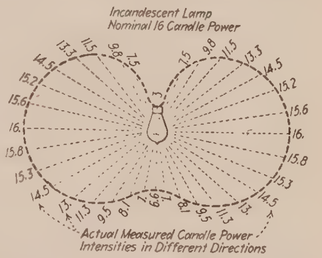


FIG. 29.—Actual candle-power intensities in different directions from a 16-c.p. carbon-filament incandescent lamp.

NOTE.—An actual light source generally emits more light in one direction than another, see Fig. 29, for example. Thus, a direct-current arc lamp (Fig. 89) gives out more light at an angle of about 45 deg. below the horizontal than in any other direction.

47. The "Candle" Is the Unit of Luminous Intensity or Candle-power, that is, of light-giving power of any light-giving source. The name "candle" was adopted for this unit because (Art. 34) candles were originally used as standard light sources. Through the endeavors of the U. S. Bureau of Standards at Washington the important countries of the world have agreed to adopt as a universal unit of luminous intensity 1 *international candle.* The quantitative relation of the value of this unit to the definite local, standard units which had been previously adopted in the different countries has been definitely fixed by agreement as shown in the following Table 51.

NOTE.*—The unit of light intensity, the candle, is a quantity not

* Steinmetz, RADIATION, LIGHT AND ILLUMINATION, page 257.

directly related to the absolute system of units, but is reproduced from specifications for comparison with maintained standards. For white light, it is probably between 0.04 and 0.02 watt.

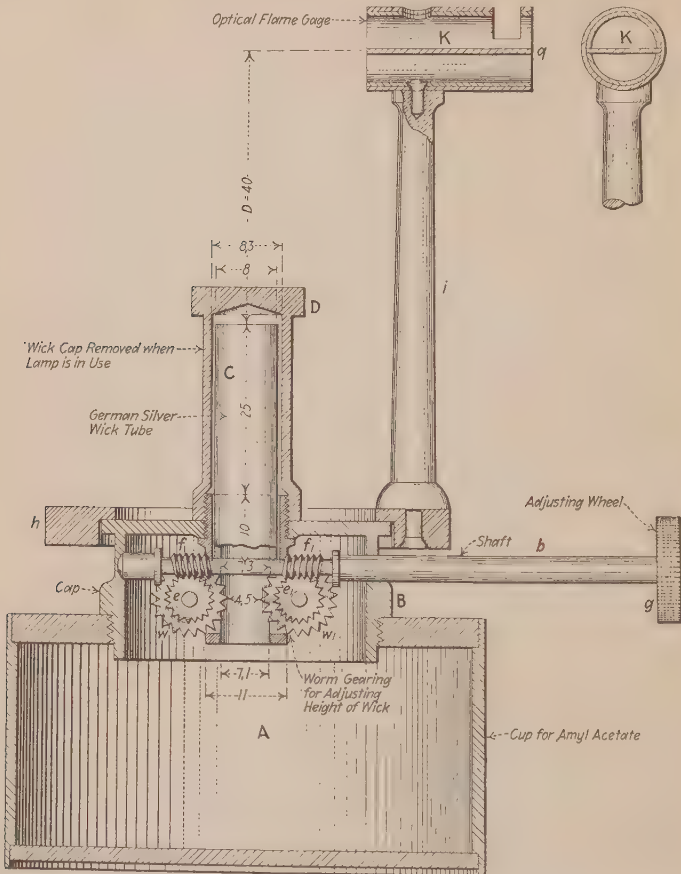


FIG. 30.—The Hefner amyl acetate lamp as developed by the physikalische reichsanstalt. (All dimensions are in millimeters and all parts are of brass except wick tube.)

48. Some Standards of Apparent Luminous Intensity which have been used in different countries are these: In Germany, the Hefner lamp (Fig. 30, which burns amyl acetate) when its flame is adjusted to a height, *D*, of 4 cm.

(1.57 in.) develops 1 *Hefner unit*, that is, 0.9 international candle of apparent luminous intensity in the horizontal direction. In France, the Carcel lamp, which burns Colza oil and develops 1 *Carcel unit*, when adjusted and burnt in compliance with certain specifications, is used. The Vernon-Harcourt pentane lamp (Fig. 31) in which pentane, a petroleum distillate, is burned as directed, was developed in England. The Hefner lamp is probably the most accurate and widely used for any of the above-described *flame standards*.

49. The Disadvantages of Flame Standards of Luminous Intensity are that they are subject to variations due to humidity, barometric pressure and similar factors. Furthermore, to insure maximum accuracy, the fuels must be of certain strengths and purities. Obviously, these restricting considerations tend to render the use of any flame standard inconvenient and to make accurate results difficult to obtain. For these reasons, properly prepared and seasoned incandescent lamps are now used to the practical exclusion of all other light sources for standards of luminous intensity.

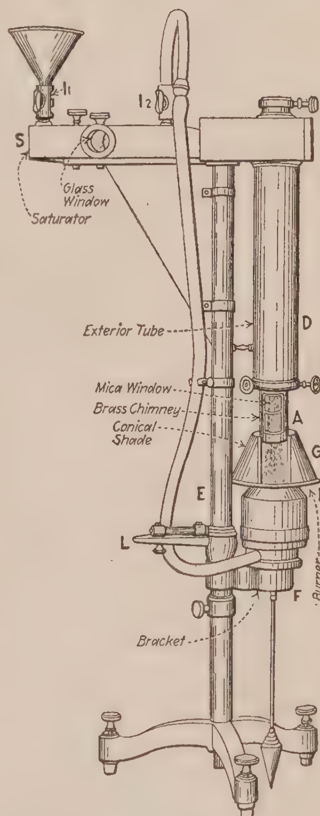


FIG. 31.—The ten-candle Harcourt pentane lamp, which uses air saturated with pentane vapor for a fuel.

50. Incandescent Lamps Make the Best Practical Standards of Luminous Intensity.—Lamps for this service are well seasoned and aged by forcing current through them for a considerable period. After being calibrated the lamp is

always operated at a voltage lower than that which would be impressed on it if it were used in ordinary illuminating service. Thus, such a standard will maintain the apparent luminous intensity for which it has been calibrated constant for an exceedingly long period. Where such lamps are used as standards they must be mounted in the photometer in a certain position because they develop the apparent luminous intensities for which they are calibrated only in a definite—usually the horizontal—direction.

51. The Quantitative Relations Between the Various Standards of Luminous Intensity are:

Names of units	International unit	American candle	Pentane candle	Hefner unit	Carcel unit	Bougie decimale
1 International candle.... *equals*	1.00	1.00	1.00	1.11	0.104	1.00
1 American candle....... *equals*	1.00	1.00	1.00	1.11	0.104	1.00
1 Pentane candle........ *equals*	1.00	1.00	1.00	1.11	0.104	1.00
1 Hefner unit........... *equals*	0.90	0.90	0.90	1.00	0.094	0.90
1 Carcel unit............ *equals*	9.61	9.61	9.61	10.66	1.000	9.61
1 Bougie decimale....... *equals*	1.00	1.00	1.00	1.11	0.104	1.00

NOTE that an International candle is one and eleven-hundredths times larger than a Hefner unit; conversely, a Hefner unit is only nine-tenths as large as an International unit. Also, a Carcel unit is about 10 times as large as an International candle, while an International candle is almost one-tenth as large as a Carcel unit.

52. The Apparent Luminous Intensity or Apparent Candle-power of a light source or of a light source in combination with a reflector is the quantity with which one must deal frequently in practice; actual luminous intensities (Art. 40) are never used except in theoretical discussions. Such an apparent luminous intensity must be taken in some specified direction. An apparent luminous intensity is the luminous intensity in candles of the true point source of such power that if it were located at the luminous center of the actual light source it would provide the same illumination—in foot-candles—on an

infinitely small area of a surface located in a position at right angles to the direction of the ray, as is actually produced by the actual light source.

EXAMPLE.—The true point source (Fig. 32) S_1 of an actual luminous intensity of 50 candles produces an illumination of 2 ft.-c. at a location P_1, a horizontal distance of 5 ft. from S_1. Then the *apparent* luminous intensity, in the horizontal direction indicated, of the incandescent-lamp-and-glass-reflector combination S_2 which also produces an illumination of 2 ft.-c. at P_2, a horizontal distance of 5 ft. from the center of S_2, must be 50 apparent candles.

NOTE.—*Examples of Apparent Candle-powers* may be given thus: Powerful electric arc in the direction of maximum apparent luminous intensity, 5,600 candles. Most powerful calcium light in the direction of maximum luminous intensity, 1,300 candles. Ordinary fish-tail gas burner, horizontal direction, 12 to 16 candles. Carbon filament incandescent lamp, 60 watts, horizontal direction, 16 candles. Tungsten in-

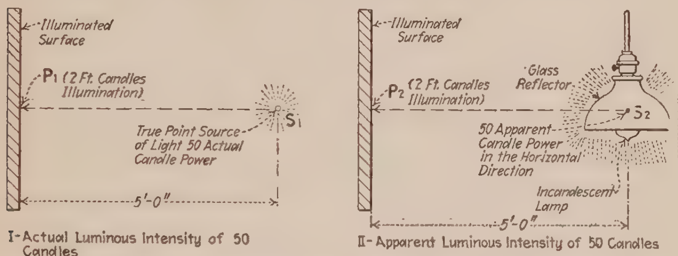


FIG. 32.—Illustrating actual and "apparent" luminous intensity.

candescent lamp, 60 watts, horizontal direction about 50 candles. Ordinary tallow candle, horizontal direction, about 1 candle.

53. The Factors Which Determine the Apparent Luminous Intensity of Any Actual Light Source are two: (1) the direction as regards the actual light source in which the apparent luminous intensity is measured; (2) of the distance of the test surface from the lamp. But, as above (Art. 37) noted, when the distance from the actual luminous source is greater than 10 times the greatest linear dimension of the light source, the variation of apparent candle-power with the distance is, in practical work, inconsiderable and hence may be disregarded. Thus, when an actual light source is provided with a reflector or shade, the combination is, in practice, treated as a unit—assuming, of course, that the resulting illumination is measured

at a location which is at least as far away from the center of the source as 10 times the greatest overall dimension of the actual light source.

NOTE.—It is obvious, then, that in practice we practically never deal with actual luminous intensities, because, in practice, we have no true point sources. When the luminous intensity of a certain lamp is stated as being, for example, 16 candles, the real meaning is that the apparent luminous intensity in a certain direction—often the horizontal direction—is 16 candles.

54. Average or Mean Luminous Intensities or Candle-powers Are Frequently Used.—Thus, we may have: (1) Mean horizontal intensity, usually designated by the symbol, I_h. (2) Mean spherical intensity, I_s. (3) Mean zonal intensity, I_{mz}. (4) Mean upper hemispherical intensity, I_{muh}. (5) Mean lower hemispherical intensity, I_{mlh}. The more important of these mean intensities, which are, of course, apparent intensities, will be defined below.

55. Mean Horizontal Luminous Intensity or Candle-power is the average of the apparent candle-powers of an actual luminous source in all directions in a horizontal plane. Incandescent lamps are usually, when they are rated in candle-power, rated by their mean horizontal apparent candle-power. Two lamps rated at the same (mean horizontal) candle-power may thus differ widely in their light-giving powers in directions above or below the horizontal.

56. Mean Spherical Luminous Intensity or Candle-power is the average of the apparent candle-powers of an actual light source taken in *all* directions. For a true point source of light, the candle-power is (because of the definition of a point source, Art. 33) the same in all directions. Hence, with a point source, the candle-power is the same as the mean spherical candle-power. But, with an actual source of light the apparent candle-powers are different in different directions, hence the necessity for introducing the quantity "mean spherical candle-power." This term is of most importance as an index (Art. 59) to the total light-giving power of a lamp or of an illuminating unit.

57. The Spherical Reduction Factor of a Light Source is the ratio of its mean spherical candle-power or luminous intensity

to its mean apparent horizontal candle-power or luminous intensity. Few, if any, actual light sources radiate uniformly in all directions. Hence, since many incandescent lamps are so constructed that they produce their maximum intensities in the horizontal direction, it is evident that the reduction factor for incandescent lamps must, usually, be less than one. By virtue of the definition as above given, the mean spherical candle-power can be obtained by multiplying the mean horizontal candle-power by the reduction factor. See Table 58, for reduction factors for lamps of certain types.

Example.—A carbon incandescent lamp with an oval anchored filament has an apparent luminous intensity in a horizontal direction of 16 c.p. What is the mean spherical candle-power of this lamp? From Table 58 the spherical reduction factor of a lamp of this type is 0.825. Hence, following the rule above: *Mean spherical candle-power* $= 16 \times 0.825 = 13.2$ *c.p.* Therefore, the mean spherical candle-power of this incandescent lamp is 13.2.

58. Factors for Obtaining Mean Spherical Candle-power. —*To obtain mean spherical candle-power multiply the mean apparent horizontal candle-power of the light source under consideration by the proper reduction factor obtained from the following table.*

Type of incandescent-lamp light source	Spherical Reduction factor
Carbon, oval anchored filament	0.825
Gem 50-watt, 20-c.p. filament	0.825
Gem 100, 125, 187, 250-watt filament	0.820
Tantalum filament	0.790
Tungsten (*Mazda*), multiple, vacuum, 105–125 volts	0.780
Tungsten (*Mazda*), multiple, vacuum, 220–250 volts	0.790
Tungsten (*Mazda C*), multiple, gas-filled, nitrogen, 105–125 volts	*0.800
Tungsten (*Mazda C*), series, gas-filled, for ordinary circuits, 60, 80, 100 c.p.	*0.760
Tungsten (*Mazda C*), series, gas-filled, for ordinary circuits, 250, 400, 600 c.p.	*0.800
Tungsten (*Mazda C*), series, gas-filled, 20-amp. circuits, 600 and 1,000 c.p.	*0.780

* The Sph. Red. Fac. for any lamp depends largely upon the contour and position of the filament. The values given are typical but may not hold for all lamps.

59. The Mean Spherical Luminous Intensity or Candle-power of a Light Source Is Sometimes Called Its Equivalent Candle-power.*—It is evident that if the average of the apparent candle-powers in all directions of a true light source be computed the resulting value will, in a sense, be the equivalent of the candle-power of a true light source which would produce the same total illuminating effect. Those sources of light, such for example, as the mercury-vapor or Moore-tube lamps, and windows or skylights from which daylight is radiated, none of which is in any sense a true light source, may be rated in equivalent candle-power. A light source equipped with a reflector may also be rated in equivalent candle-power. When used in this sense, *equivalent candle-power* means the candle-power of a true point source would provide the same total light flux as the actual light source unit under consideration.

NOTE.—If, as outlined in following Art. 66 the total light flux in lumens of a source be divided by the constant 4π, or 12.57, the mean spherical or equivalent luminous intensity in candles will be the result. See the examples there given.

60. Mean Lower Hemispherical Candle-power is the average of the apparent candle-powers of the light source in all directions in the lower hemisphere. When applied to incandescent lamps, the lamp is assumed to have the bulb down, base up. This term is of little importance where lamps are to be used with reflectors.

61. Luminous Flux Is Measured in Lumens.—That is, the *lumen* is the unit of flux and it represents a definite rate of light emission. The concept of light flux was briefly discussed in Art. 31 which should be reviewed by the reader before he proceeds. Since light, or "luminous flux" is merely the name that has been assigned to a flow of light energy or light waves in the æther, it follows that the lumen is the unit in which this flow is measured. "The lumen is a definite rate of light emission." As suggested in Art. 33, the ideas and units used in the science of illumination are all developed from the fundamental notion of luminous intensity or

* See Steinmetz, RADIATION, LIGHT AND ILLUMINATION, page 258.

candle-power. The relation of the unit of light flux, the lumen, to the unit of luminous intensity, the candle, will now be shown. However, before the reader proceeds, he should understand the meaning of the term "unit solid angle."

62. A Unit Solid Angle (sometimes called a *steradian*) is the unit of solid angular measurement. It may be defined as that solid angle, subtended at the center of a sphere of unit radius, by a unit area on the surface of the sphere. Also, a unit solid angle may be defined as the solid angle subtended at the center of a sphere by an area on its surface equal to the square of the radius.

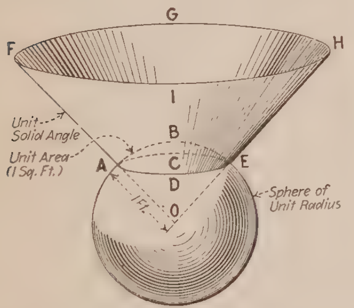


FIG. 33.—Showing the idea of unit solid angle.

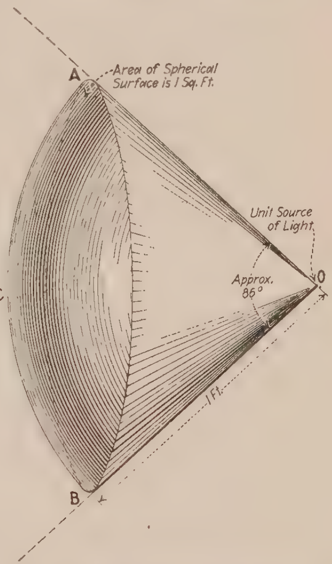


FIG. 34.—Illustrating the unit solid angle of conical form.

EXAMPLE.—Fig. 33 illustrates the idea. The sphere there shown is of unit, 1 ft., radius. Area *ADEC*, subtended by the solid angle shown on the surface of the sphere is of unit, that is, 1 sq. ft., area. Hence the solid angle, *OFIGH*, which may be considered as extending into space, is a unit solid angle. As suggested in Fig. 34, the angle at the apex *O* is approximately 86 deg. If a sphere of 1 ft. radius is considered and on the surface of that sphere a circle of such diameter is drawn that it will include 1 sq. ft. area on the surface of the sphere, then, the cone formed by all of the elements or imaginary lines connecting the circle with the center of the sphere, is a unit solid angle. A unit solid angle may be of square-pyramid or of other forms as well as of conical form. Thus, the solid angle *OEHGF* (Fig. 35) is a unit solid angle because its faces or sides

intercept at unit, 1 ft., radius a unit, 1 sq. ft., spherical area *ABCD*. It follows that the area *EFGH* which is 2 ft. radially distant from *O* must be an area of 4 sq. ft. An area 3 ft. radially distant from *O* comprised within the sides of the unit angle shown would be 9 sq. ft.

NOTE.—Although the distances in the above discussion are expressed in feet and the areas in square feet, any other similar units of measure might have been used instead without affecting the accuracy of the truths stated. Thus, the radii might have been expressed in inches, as 1 in. and the area subtended as 1 sq. in.—or the radius might have been expressed as 1 meter and the area as 1 sq. meter.

63. There are 12.57 Unit Solid Angles about Any Point in Space.—That is, any sphere contains 12.57 unit solid angles. That this is true may be shown thus: The superficial area of any sphere $= 4 \times \pi \times r^2$. That is, $4 \times 3.1416 \times radius^2 = 12.57 \times radius^2$. Hence, the superficial (surface) area of a sphere of a radius of 1 ft. is: $12.57 \times 1\,ft. \times 1\,ft. = 12.57\,sq.\,ft.$ Now, by definition, as above, a unit solid angle subtends unit area (1 sq. ft.) on the surface of a sphere of unit (1 ft.) radius. It follows then that if there is 12.57 sq. ft. of area on the surface of a sphere of unit radius, there must be 12.57 unit solid angles in the sphere. Consideration will show that there will be 12.57 unit solid angles in any sphere.

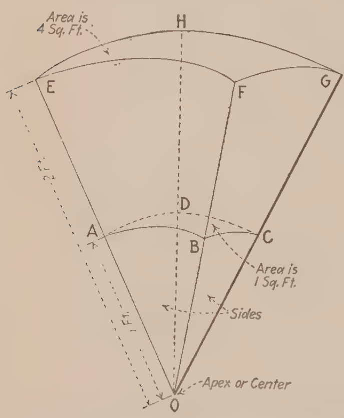


FIG. 35.—Illustrating a unit solid angle of "square pyramid" form.

64. A Lumen of light flux is the flux emitted in a unit solid angle (steradian) by a point source of 1 c.p.* That is, it has been agreed to call that quantity of light flux which is radiated in a unit solid angle, from a 1-candle true point source, 1 lumen.

EXAMPLE.—If, as diagrammed in Fig. 36, a 1-candle true point source of light be located at the apex of the unit solid angle there shown, the amount of light flux which will illuminate the surface on which it falls in

* A. I. E. E. STANDARDIZATION RULE 857.

that unit solid angle is, by definition, 1 lumen. If the point source were of 2-candles intensity then 2 lumens of flux would be included in the solid angle. If the point source were of 3-candles intensity there would be 3 lumens in the solid angle—all of which follows from the definition of the lumen, as above.

65. A Luminous True Point Source of One-candle Intensity Generates 12.57 Lumens of Light Flux in the space around it. That this is true follows from the definitions of the lumen (Art. 64) and of a unit solid angle (Art. 62). A lumen is the flux in a unit solid angle and there are 12.57 unit solid angles about any point in space. Hence, the total light flux emitted in all directions by a point source of 1 candle-power must, as above stated, be 12.57 lumens.

EXAMPLE.—If the point source P shown, in Fig. 21, is of 1-candle intensity then the total light flux, radiated by it in all directions, which illuminates the interior surface of the hollow sphere, must be 12.57 lumens. If the point source had an intensity of 2 candles, then the total flux emitted would be: $2 \times 12.57 = 25.14$ *lumens.*

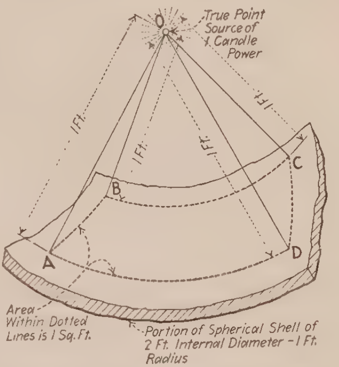


FIG. 36.—Diagrammatic definition of the lumen.

The above statement can be written into a formula thus:

(3) $$F = I \times 4 \times \pi \qquad \text{(lumens)}$$

or

(4) $$F = I \times 12.57 \qquad \text{(lumens)}$$

and

(5) $$I = \frac{F}{12.57} \qquad \text{(actual candles)}$$

Wherein.—F = total light flux radiated by a point source, in lumens. I = actual luminous intensity or candle-power of the true point source, in candles. Note as above written the equations apply only to a *true point source,* hence they are never used in actual practice.

66. The Mean Spherical Candle-power of Any Actual Luminous Source Multiplied by 12.57 Gives the Total Lumens

generated by that source. As suggested in Art. 59, the mean spherical apparent candle-power of any actual light source —or a light-source-and-reflector combination—may be considered as the equivalent of the actual candle-power of an equivalent true point source. Hence, it may, on the basis of the explanation given in the preceding Art. 65, be written that:

(6) $$F = 12.57 \times I_e \qquad \text{(lumens)}$$

(7) $$F = 12.57 \times I_{scp} \qquad \text{(lumens)}$$

and

(8) $$I_e = \frac{F}{12.57} \qquad \text{(equivalent candles)}$$

or

(9) $$I_{scp} = \frac{F}{12.57} \qquad \text{(mean spherical candle-power)}$$

Wherein.—F = total flux generated by the actual light source, in lumens. I_e = equivalent luminous intensity or candle-power, of an actual light source, in candles. I_{scp} = mean spherical candle-power, in candles.

Example.—If the equivalent or mean spherical candle-power of a certain light source is 40 candles what light flux, in lumens, will be radiated by that source? Solution.—Substitute in equation (7) above: $F = 12.57 \times I_{scp} = 12.57 \times 40 = 502.8$ *lumens.*

Example.—A 200-watt Tungsten gas-filled incandescent lamp produces or radiates 2,680 lumens. What is the mean spherical candle-power of this lamp? Solution.—Substitute in the above equation (9): $I_{scp} = F \div 12.57 = 2{,}680 \div 12.57 = 214$. That is, the mean spherical or equivalent candle-power of this unit would be 214 candles.

67. The Luminous Output of Any Light Source Can Be Measured in Lumens,* that is, in units of flux of light. Thus we may measure, in lumens, the diffused daylight entering the windows of a room or the visible radiation of the mercury-vapor lamp or a Moore tube, as well as that of a true point source, by adding all of the flux densities intercepted by any surface enclosing the source of light.

68. A Luminous Rating is now usually given to light source. That is, it is now generally recommended by the important Engineering Societies that the luminous output of incan-

* Steinmetz, Radiation, Light and Illumination, page 257.

descent lamps, and in general of all other light sources, be rated on the basis of the total lumens emitted by the source. This method will, doubtless, ultimately supersede the older indefinite method of rating the illuminants on the basis of their mean apparent horizontal candle-powers.

EXAMPLE.—At the efficiencies now obtaining a 25-watt carbon-filament lamp develops 84 lumens. A 25-watt vacuum Tungsten lamp develops 234 lumens. A 1,000-watt gas-filled Tungsten lamp develops 18,000 lumens.

69. A Lumen-hour is the unit of light quantity. The quantity of light radiated by a source is the product of the total luminous flux and the time.

EXAMPLE.—From a lamp having a mean spherical candle-power of 10, the total flux radiated will be: $10 \times 12.57 = 125.7$ *lumens*. If the lamp maintains this flux for 100 hr.—*i.e.*, does not drop in candle-power—it will, at the end of the 100 hr. have radiated: 125.7 *lumens* $\times$ 100 *hr.* $=$ 12,570 *lumen-hr.*

70. The Lumens per Watt Generated is equal to the total light flux in lumens from a light source divided by the wattage rating of the source.

71. Illumination is the light flux density impinging on the surface of an illuminated object.* Illumination is measured in a unit called the foot-candle, which will be described in Art. 73. Light or luminous flux can be thought of (Art. 32) as being comprised of many rays or lines of light which emanate from the luminous unit and impinge on the illuminated object from which they are reflected (Art. 117) to the retina (Art. 22) of the human eye. Each unit of light flux—each lumen—may be thought of as representing a certain definite number of these flux lines.

On this basis the greater the number of these rays which impinge on the object, the greater will be its illumination—or density of the incident light flux over its surface. The fewer the rays which impinge on the object, the less will be the illumination or density incident light flux. Note particularly that the term "illumination" *can be only properly applied to designate the light flux density incident on illuminated*

* Steinmetz, RADIATION, LIGHT AND ILLUMINATION, page 259.

objects. Hence it is not proper to refer to the "illumination of a light source" but it is correct to refer to the "illumination produced by a light source." Illumination refers only to something that is illuminated.

Illumination measures the density of the flux incident upon any surface and that brightness (Art. 86) measures the density of the flux emitted from a surface either as the result of light emission or light diffusion.*

72. Light Flux Density means the quantity of flux per unit area of the illuminated surface—that is, the quantity of flux, in lumens, per square foot area. To obtain a concrete numerical expression to represent the density of anything on a surface, the number of things on the entire surface is divided by the number of unit areas in the surface:

EXAMPLE.—If there are 274,300 people populating an area of 100 sq. miles the density of population in this district is: 274,300 ÷ 100 = 2,734 *inhabitants per sq. mile.* Also, if in a magnetic circuit there are a total of 846,760 lines of force and the circuit has an area of 8 sq. in. the magnetic flux density in this circuit would be 846,760 ÷ 8 = 105,845 *lines of force per sq. in.*

Thus, as will be shown, to obtain illumination—which is the density of the incident light flux—the light flux incident on an area, in lumens, is divided by the area in square feet. The result will, then, be the light flux density *in lumens per sq. ft.* or in foot-candles.

73. The Foot-candle is the unit of illumination or of luminous flux density. It may be defined in two ways—both of which really means the same thing.

On the basis of the fundamental concept of luminous intensity:

An illumination of 1 ft.-c. is that illumination which is produced by a 1-c.p., point source, on a surface located just 1 ft. distant from the point source.

EXAMPLE.—If, in Fig. 37, the luminous source, *S*, be assumed to be a true point source of luminous flux, then the illumination—density of the incident luminous flux—at the point *A* on the vertical surface which is illuminated would, by definition as above, be 1 ft.-c. The illumination at other points on the vertical surface, for example *BCDE*, will be less

* Wickenden, ILLUMINATION AND PHOTOMETRY, page 15.

than 1 ft.-c. The reason for this is that A is the only point which is exactly 1 ft. distant from S. The other points on the vertical surface are more than 1 ft. distant from S. If S in Fig. 37 be taken as an actual source of light and its apparent luminous intensity (Art. 52) in the direction SA is 1 candle, then the illumination at A, 1 ft. distant from S, will be 1 ft.-c. (assuming that the conditions of Art. 37 are satisfied), but the illumination at the other points in the vertical surface will be less than 1 ft.-c.

On the basis of the concept of luminous flux the foot-candle may be defined thus:

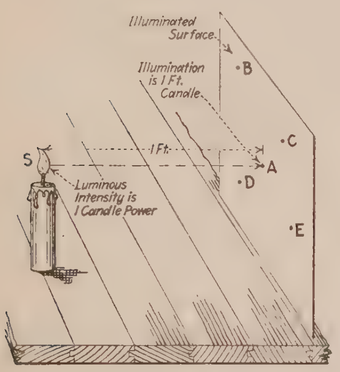


FIG. 37.—Illustrating the concept of an illumination of 1 ft. candle.

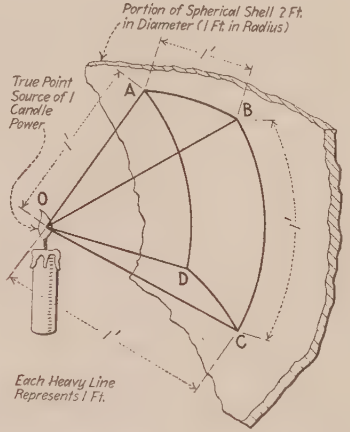


FIG. 38.—Flux of light in unit solid angle.

An illumination of 1 ft.-c. is that illumination produced on every point on a surface having an area of 1 sq. ft. if 1 lumen of light flux is spread uniformly over it.

EXAMPLE.—In Fig. 38 the surface $ABCD$ is illuminated to a density of 1 ft.-c., because (Art. 64) the solid angle $OABCD$ contains a lumen of flux and the area $ABCD$ is drawn to be 1 sq. ft. That the interior area $ABCD$—every point in it—would be illuminated to 1 ft.-c. density follows from the fact that $ABCD$ is inscribed on the inner surface of a spherical shell every point in which is exactly the same distance—1 ft.—from the point source, O.

NOTE that a foot candle—a luminous density of 1 ft.-c.—is equal to a flux density of 1 lumen per sq. ft.

74. The Lux is the unit of illumination employed when the metric system of measurements is used. It is the luminous

flux density on a surface produced by a 1-c.p. point source at a distance of 1 meter from the surface. Or, it is the illumination produced by 1 lumen spread over 1 sq. meter area. That is, 1 *lux* = 0.0929 *ft.-c.*, 1 *ft.-c.* = 10.76 *lux*.

75. The Intensities of Natural Illumination* vary very greatly, ranging up or down according to relation of the point considered to windows and sunlight.

EXAMPLES.—The intensity of the diffuse illumination near a south window may rise to 20 ft.-c. or more; with less brilliant exposure it may be 10, or 5 or 3 ft.-c., and so on down as one passes to less favorable positions and gets down to fractions of a foot-candle. The illumination, for example, where this paragraph is being written near a west window on a rainy day is about 3 ft.-c., while 10 ft. further within the room it has fallen to less than 0.5 ft.-c. by which it is difficult to read coarse print. So far as ordinary work goes any illumination above say 2 ft.-c. is about equally good. When daylight drops materially below this, one must resort to artificial light, and there is a strong tendency to use much more than is necessary to the detriment of the eyes. Under a desk lamp an illumination of 10 ft.-c. is not an exceptional amount, but it is more than double that which can generally be advantageously utilized by the eye.

76. The Formulas for Computing Illumination in Foot-candles will now be given. These follow from the definition (Art. 73) of the foot-candle. If the luminous flux, in lumens, impinging on a surface be divided by the area in square feet of that surface, the density of illumination in foot-candles on that surface will be the result. The unit foot-candle is then really equivalent to *lumens per square foot*. That is, in general:

$$\text{(10)} \qquad \textit{Illumination in foot-candles} = \frac{\textit{flux in lumens}}{\textit{area in square feet}}$$

hence

$$\text{(11)} \qquad \textit{Flux in lumens} = (\textit{illumination in foot-candles}) \times (\textit{area in square feet})$$

and

$$\text{(12)} \qquad \textit{Area in square feet} = \frac{\textit{flux in lumens}}{\textit{illumination in foot-candles}}$$

These equations will now be given with letters instead of words for symbols. But two specific conditions must be considered:

* Bell, STANDARD HANDBOOK.

(1) *Where the illumination—flux density—over the surface is uniform*, as, for example, in Fig. 36. (2) *Where the illumination over the surface is non-uniform*, as, for example, in Fig. 37.

When the illumination is non-uniform:

(13) $$E_{av} = \frac{F}{S} \quad \text{(average foot-candles)}$$

hence

(14) $$S = \frac{F}{E_{av}} \quad \text{(square feet)}$$

and

(15) $$F = S \times E_{av} \quad \text{(lumens)}$$

Then, for uniform illumination:

(16) $$E = \frac{F}{S} \quad \text{(foot-candles)}$$

hence

(17) $$S = \frac{F}{E} \quad \text{(square feet)}$$

and

(18) $$F = S \times E \quad \text{(lumens)}$$

Wherein.—E_{av} = average illumination of the non-uniformly illuminated surface, in foot-candles. E = illumination at every point of the uniformly illuminated surface, in foot-candles. S = area of the surface illuminated in square feet. F = luminous flux incident on the surface, in lumens.

EXAMPLE.—If, in Fig. 39, a uniform flux of light of 1 lumen impinges on an area of 1 sq. ft., as shown at *I*, then the illumination of that area will be 1 ft.-c. If a flux of 1 lumen impinges on an area of 4 sq. ft., as shown at *II*, then the illumination on that surface will be: 1 *lumen* ÷ 4 *sq. ft.* = ¼ *ft.-c.*

EXAMPLE.—In Fig. 40, *I*, 6 light units illuminate the floor area of 880 sq. ft. shown. Assume that each one of these units generates 800 lumens, and assume, that only half or 50 per cent. of the light generated by these units impinges on the floor. What will be the average illumination over the floor of this room. SOLUTION.—Since there are 6 light units and each generates 800 lumens, the total luminous flux generated by them in this room is: 6 × 800 *lumens* = 4,800 *lumens* generated. Since only 50 per cent. of the light generated impinges on the floor, the

flux incident on the floor will be: 4,800 *lumens* × 0.50 = 2,400 *lumens*. Now, to determine the illumination density on the floor, substitute in

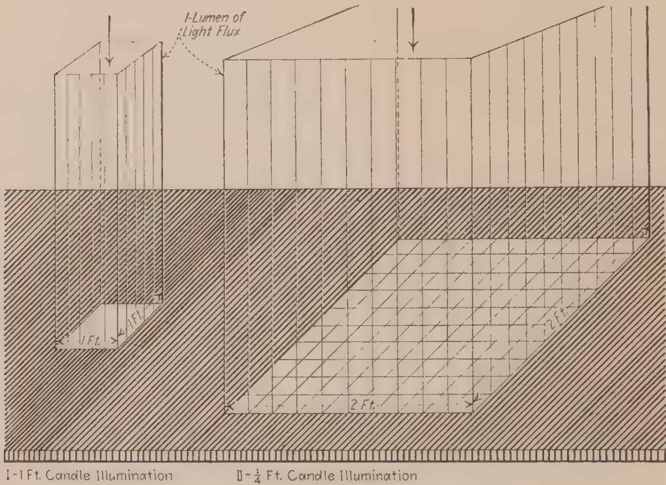


FIG. 39.—Illustrating the ideas of light flux and illumination.

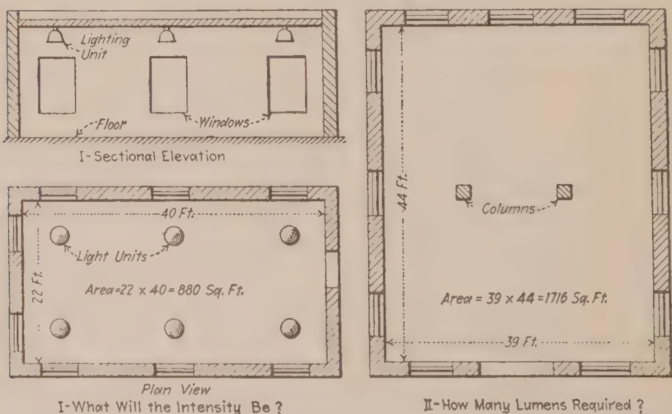


FIG. 40.—Problems illustrating the application of the illumination formulas.

equation (13) above: $E_{av} = F \div S = 2{,}400 \div 880 = 2.7$. Hence, the *average* illumination over this floor would be 2.7 ft.-c.

EXAMPLE.—Assume that it is desired to illuminate the floor area of 1,716 sq. ft., shown in Fig. 40, *II*, to an average illumination density of

4 ft.-c. How many lumens of light flux would be necessary to effect this result, assuming that only 25 per cent. of the flux generated by the lighting units impinges on the floor? SOLUTION.—If all of the flux generated by the lighting units reached the floor, then there would be required (equation (15): $F = S \times E_{ax} = 1{,}716 \times 4 = 6{,}864$ *lumens*. Since only 25 per cent. or one-fourth of the flux generated by the units reaches the floor, the lighting units would have to develop: $4 \times 6{,}864 = 27{,}456$ *lumens*. It should be understood that the *average* illumination over this floor area would be 4 ft.-c. With the lighting units as ordinarily used, some locations on the floor would be illuminated to a greater density than 4 ft.-c. and some locations would be illuminated to a lesser density.

EXAMPLE.—The lighting unit shown in Fig. 41 emits as shown a total flux of 1,200 lumens. What area would this flux illuminate to an average density of 6 ft.-c.? SOLUTION.—Substitute in equation (13) $E_{av} = F \div S = 1{,}200 \div 6 = 200$ *sq. ft.*

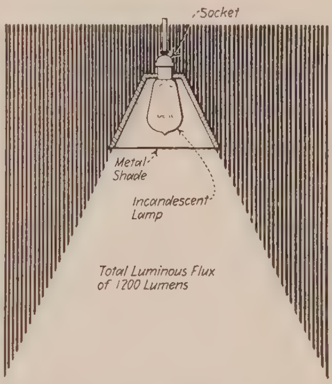


FIG. 41.—What area will this flux illuminate to a density of 6-foot candles?

77. Foot-candles Illumination Varies Directly as the Luminous Intensity in Candles of a Source and Inversely as the Square of the Distance between the point source (or a source which may be considered as a point source) and the point in space where the illumination is reckoned. This proposition was discussed in Art. 36 but, however, without any reference to a unit of flux, the lumen, or a unit of illumination, the foot-candle. Now consider a true point source (Art. 33) of 1-c.p. intensity at the exact center of a hollow sphere as shown in Fig. 42, at I. This hollow sphere has a radius of 1 ft. Since every point on the interior surface of the shell must necessarily be just 1 ft. distant from the point source, its entire interior surface would, because of the definition of a foot-candle (Art. 73), be illuminated to a density of 1 ft.-c. The area of the interior surface of the shell of 1 ft. radius is (Art. 63) 12.57 sq. ft. Also the total light flux illuminating this interior surface is (Art. 65) 12.57 lumens.

Now, if the same 1-c.p. light source be placed at the center of a shell (Fig. 42, *II*) of 2 ft. radius, the flux will be the same, 12.57 lumens, as in *I*. However, this flux is in *II* "spread out" over an area of: $4 \times \pi \times r^2 = 4 \times 3.1416 \times 2 \times 2 = 50.26$ *sq. ft.* Now, 50.26 sq. ft. is four times 12.57 sq. ft. Hence, since the flux in *II* is distributed over four times the area that it covers in *I*, the illumination—flux density—in *II* will be one-fourth of that of *I*. That is, the illumination on the inner surface of *II* is ¼ ft.-c.

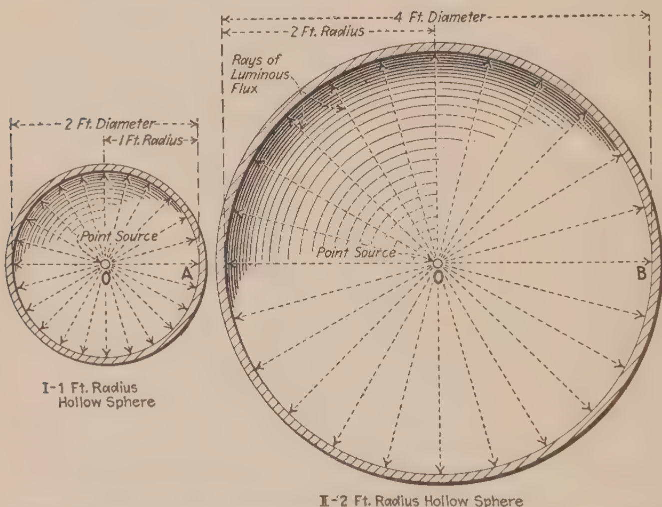


FIG. 42.—Showing how illumination must vary as the square of the distance.

NOTE.—From a mere inspection of the illustrations of Fig. 42, it is evident that the illumination, that is, the light flux density (represented roughly by the "closeness together" of the dotted lines which indicate light flux) on the inner surface of *I* is much more dense than that on the inner surface of *II*.

Thus the distance in *II* from the point source to the illuminated surface is two times the corresponding distance in *I*. By doubling the distance, the illumination has been reduced to one-fourth (the square of 2 is: $2 \times 2 = 4$, and the inverse of 4 is ¼) hence it is evident that the illumination

varies inversely as the square of the distance. It is also evident that if a luminous point source of 2 c.p. were substituted for the 1-c.p. source, as shown, the illumination incident on the interior surface of I would be 2 ft.-c. and that the illumination on the interior surface of II would be ½ ft.-c. Hence it follows that illumination also varies directly as the luminous intensity of the source.

NOTE.—In the above discussion a point source illuminant was used because, as noted in Art. 33, the units and ideas utilized in the art of illumination are all based on the fundamental concept of a point source. If an *actual* light source of 1 candle equivalent or mean spherical intensity (Art. 59) were substituted for the point source, the total flux then impinging on the interior surfaces of I and of II would, as before, be 12.57 lumens (Art. 65). Then, the average illumination on the interior of I would be 1 ft.-c. and the average illumination on the interior of II would be ¼ ft.-c., but with an actual light source at their centers, the illumination over the interior surfaces of these two shells would not be uniform. At certain points it would be greater than 1 ft.-c. and ¼ ft.-c., respectively, and at other points it would be less—but the average would be 1 and ¼ ft.-c., respectively, as above stated.

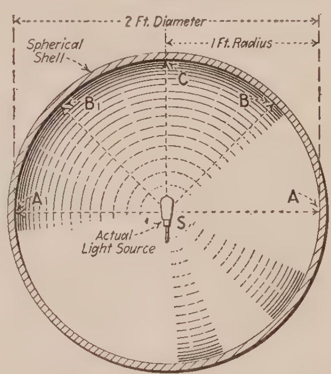


FIG. 43.—Actual light source in a spherical shell.

EXAMPLE.—If an actual light source (Fig. 43) having an apparent intensity of say 1 c.p. in direction SA be placed at the center of a spherical shell of 1 ft. interior radius, then the light flux density at the point A will be 1 ft.-c. But the apparent intensity of S in the direction SB might possibly be about 0.8 c.p., in which case (on the same basis as above) the intensity at B would be 0.8 ft.-c. Likewise, if the apparent intensity of S in the direction of SC is 0.5 c.p., then the illumination at point C will be 0.5 ft.-c.

78. Normal Illumination (Art. 102) will now be considered. The illumination of the interior of the spherical shells of Fig. 42 is normal illumination because any small portion of the circumference of a circle is at right angles to a radius between it and the center of the circle. All of the light flux lines in Fig. 42 are radial. Fig. 44 also shows examples of normal

illumination where the lighted surface lies at right angles to the ray. Now, it was shown in Art. 77 that the density of illumination in Fig. 42 varied directly as the luminous intensity and inversely as the square of the distance. Therefore, it may *for normal illumination* be written:

$$E_n = \frac{I}{d^2} \quad \text{(foot-candles)} \tag{19}$$

hence

$$I = E_n \times d^2 \quad \text{(candle-power)} \tag{20}$$

and

$$d = \sqrt{\frac{I}{E_n}} \quad \text{(feet)} \tag{21}$$

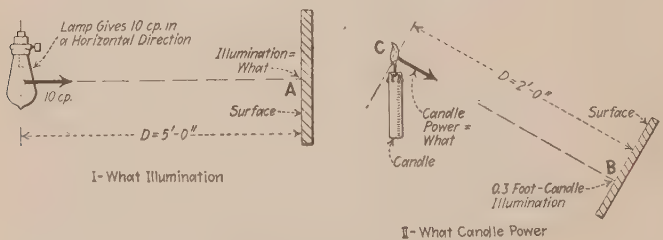


FIG. 44.—Illustrating the inverse square law.

Wherein.—E_n = the illumination, in foot-candles, on a surface normal or at right angles to the direction of the incident ray at the point under consideration. I = the luminous intensity of a true point source, in candles; for an actual point source I may be taken as the apparent candle-power in the direction under consideration, if the distance from the actual light source to the surface is greater than 10 times the greatest dimension of the light source (Art. 37). d = distance, in feet, between the source of light and the point under consideration on the illuminated surface.

EXAMPLE.—In Fig. 45, O represents an actual source of light which has an apparent luminous intensity in the horizontal direction $O - O_2$ of 1 candle. From what has preceded it follows that the illumination density at the point O_1, 1 ft. distant from O, will be 1 ft.-c. It also follows that, since illumination varies as the square of the distance from the source, the density at point O_2 will be ¼ ft.-c. It also follows

that the average illumination density for the area *QRST*, 2 ft. distant from *O*, will be one-fourth the average density or illumination of *MNOP*. This situation is shown diagrammatically by the shading on the squares A_2 and A_1.

EXAMPLE.—In Fig. 44, *I*, what is the density of illumination at point *A* on the surface. The incandescent lamps develops an apparent intensity of 10 c.p. in a horizontal direction and the surface is 5 ft. from the lamp. SOLUTION.—Substitute the values in formula (19) $E_n = I \div d^2 = 10 \div (5 \times 5) = 10 \div 25 = 0.4$ *ft.-c.* Therefore, the illumination at the point *A* is 0.4 ft.-c.

EXAMPLE.—In Fig. 44, *II*, the illumination at the point *B* is 0.3 ft.-c and the surface is 2 ft. from the light source. What is the apparent

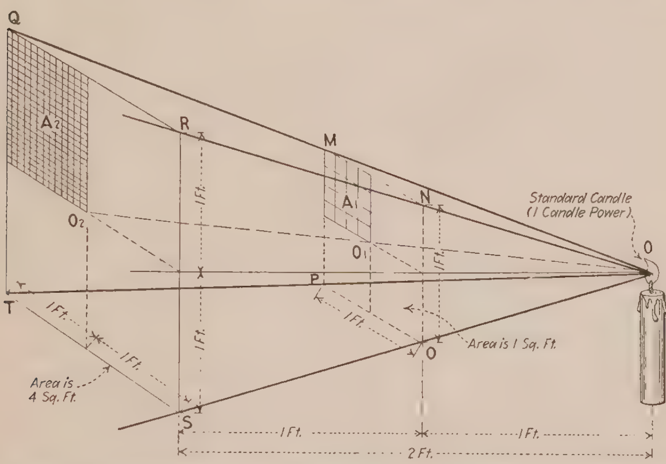


FIG. 45.—Another illustration of how luminous density varies inversely as the square of the distance.

c.p. of the light source in the direction *CB*? SOLUTION.—Substitute the values in formula (20) $I = E_n \times d^2 = 0.3 \times 2 \times 2 = 1.2$ *c.p.* Therefore, the candle develops an intensity of 1.2 c.p. in the direction *CB*.

78. In Practice the Rays from an Actual Light Source Are Seldom Normal to the Surfaces Illuminated.—Fig. 46 illustrates a typical situation wherein light source *O* is used for illuminating the room. The rays impinge on the walls, floor and ceiling. Only a few of the infinite number of rays which might be shown are illustrated. But, of the rays shown or which might be shown in this view, there are only three, *OA*,

OB and *OC* which are normal—at right angles—to the surface which they illuminate. It follows then that the simple inverse square law stated in equation (19) does not directly apply in many cases. It does not apply where the light beam impinges obliquely—as do all the rays in Fig. 46—except *OA*, *OB* and *OC*.

79. In Computing the Illumination on a Surface When the Surface Is Not Normal—Not at Right Angles to the Incident Ray—the truths delineated in Fig. 47 should be considered. The surface *wxyz* lies in a horizontal plane which, however, is

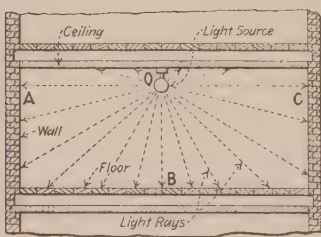


FIG. 46.

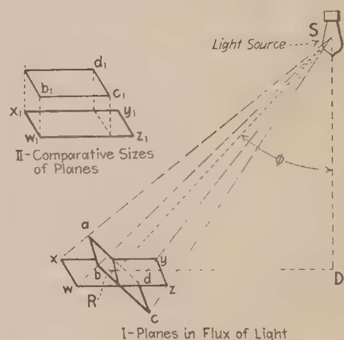


FIG. 47.

FIG. 46.—Showing that in practical illumination, few of the rays are normal to the surface illuminated.

FIG. 47.—Illustrating the theory of the cosine law.

not normal—at right angles—to their dection of the light ray or flux line *SR*. The surface *abcd* is normal to *SR*. Now, it is obvious from the construction of the diagram that the same total light flux—lumens—impinges on *abcd* as on *wxyz*. But, *wxyz* is, as shown at *II*, a larger area than *abcd*. Since the same total flux illuminates both areas it is evident that the flux density on the larger area *wxyz*, which is inclined to the ray *SR*, must be less than the flux density on the smaller area *abcd*.

80. It can be shown that the flux density on a surface inclined to the direction of the light ray varies as the cosine (see the author's PRACTICAL ELECTRICITY for an explanation of the term cosine) of the angle (ϕ for surface *wxyz* in Fig. 47)

between the line SD, normal to the surface illuminated, and the direction, SR, of the incident ray to the point illuminated. Thus, the cosine (abbreviated cos) of the angle, ϕ, may be thought of as a sort of reduction factor or multiplier. Hence, putting the above statement, combined with those of Art. 78 into a formula, it may be written:

$$E = \frac{I}{d^2} \times (\cos \phi) \qquad \text{(foot-candles)} \tag{22}$$

hence

$$d = \sqrt{\frac{I \times (\cos \phi)}{E}} \qquad \text{(feet)} \tag{23}$$

and

$$I = \frac{E \times d^2}{\cos \phi} \qquad \text{(candle-power)} \tag{24}$$

Wherein (see Fig. 48).—E = the illumination at the point on the surface under consideration, in foot-candles. I = the luminous intensity, in candles, of the true point source, or it may be the apparent intensity, in candles, in the direction under consideration, of an actual light source. d = distance, in feet, from the point under consideration, to the light source. $\cos \phi$ = cosine (a value to be taken from a table of cosines, see Art. 254) of the angle between the incident ray and a line normal or at right angles to the illuminated surface as above described.

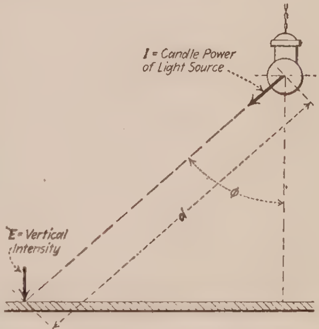


FIG. 48.—Notation for the first cosine-law formula.

NOTE that the illumination on any surface is proportional to the number of flux lines per unit area impinging thereon. The direction of the lines (whether they are normal or inclined) in relation to the surface is immaterial.

81. It Should Be Noted That the Above Equations are Perfectly General in their application, that is, equations (22), (23) and (24). They apply even if the illuminated surface

is not inclined, but is normal to the incident ray. If the surface is normal to the ray, then the angle between the ray and the normal line is 0 deg. and the cos of 0 deg. (see Table 254) is one (1). Hence, where the illuminated surface is normal to the area, the cos ϕ "reduction factor" is 1, and multiplying $I \div d^2$ by 1, does not change the value of $I \div d^2$. Usually, in practice one is interested in computing the illumination on either the horizontal or the vertical surface. Therefore, formulas derived from the general equations in preceding Art. 80 for computing the illumination on vertical and horizontal surfaces will be given.

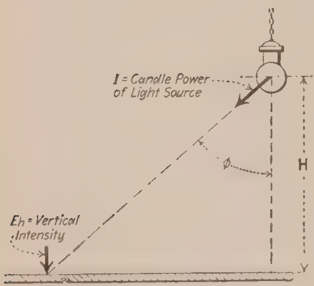


FIG. 49.—Notation for the second cosine-law formula.

82. To Compute the Illumination of a Point on a Horizontal Surface (Art. 103), the following equation, which is a convenient form and which may be derived from that of Art. 80 can be used:

(25) $$E_h = \frac{I}{H^2} \times (\cos \phi)^3 \qquad \text{(foot-candles)}$$

hence

(26) $$I = \frac{E_h \times H^2}{(\cos \phi)^3} \qquad \text{(candle-power)}$$

and

(27) $$H = \sqrt{\frac{I}{E_h} \times (\cos \phi)^3} \qquad \text{(feet)}$$

Wherein (Fig. 49).—E_h = illumination, in foot-candles, at a point on a horizontal surface. H = vertical height, in feet, of the light source above the horizontal surface illuminated. All of the other symbols have the same meanings as listed above.

EXAMPLE.—An example is given under following Art. 83.

83. The Value for Candle-power for Use in the Above Formulas should not be taken as the nominal rated candle-power of the light source but should be taken from a photo-

metric curve (see Fig. 29) or from manufacturer's data, as the candle-power in the particular direction under consideration, as illustrated in the following examples.

EXAMPLE.—A lamp is located 12 ft. above (Fig. 50) and to the right of a table in such a position that the angle ϕ is 60 deg. Assume that the apparent candle-power of the lamp in this direction (30 deg. below the horizontal) is 40 candles. What is the horizontal intensity at the table, in other words, what is the intensity of illumination on the table? SOLUTION.—From Table 254 of cosines, it will be found that cos 60 deg. = 0.5. Now, substitute the values from Fig. 50 in the formula (25): $E_h = I \times (\cos\ \phi)^3 \div H^2 = (40 \times 0.5 \times 0.5 \times 0.5) \div (12 \times 12) = (40 \times 0.125) \div 144 = 0.035$ *ft.-c.* Therefore, the horizontal illumination at point I_h is 0.035 ft.-c.

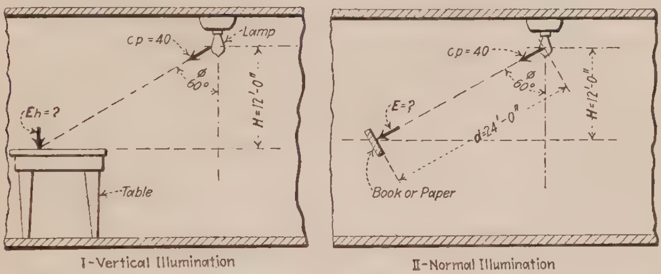


FIG. 50.—Example of computing vertical and normal illumination.

EXAMPLE.—What would be the illumination on a book held at right angles to a beam of light, as in Fig. 50, *II*, the distance from the book to the light source being 24 ft.? SOLUTION.—Substitute in formula (19): $E_n = I \div d^2 = 40 \div (24 \times 24) = 40 \div 576 = 0.070$ *ft.-c.* Therefore the illumination at the point I on a book held at right angles to the beam of light would be 0.070 ft.-c.

84. The Calculation for Intensity on a Vertical Surface (see Art. 104 for "vertical illumination") is similar to that for the intensity on a horizontal surface. The formula is (see Fig. 51)

$$E_v = \frac{I}{d^2} \times (\text{sine}\ \phi) \qquad \text{(foot-candles)} \tag{28}$$

or

$$E_v = \frac{I}{S^2} \times (\text{sine}\ \phi)^3 \qquad \text{(foot-candles)} \tag{29}$$

Wherein.—All of the symbols have the same meanings as above,

except that E_v = the intensity of illumination, in foot-candles, on the vertical surface. S = horizontal distance, in feet, from a point directly under the lamp to the surface.

85. A Caution Regarding the Use of the Preceding Formulas for computing illumination should be understood. The illumination densities derived with the above formulas give the density due only to the direct light from the one light unit under consideration. In practice this derived value is always increased by a certain amount because of diffusely reflected light. This increase may be relatively large if the ceiling, walls and other objects in the room are light in color and have a high coefficient of reflection. But it is almost negligible in spaces where the walls may be of dark brick and

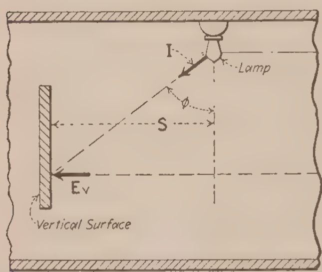


FIG. 51.—Notation for "illumination on vertical-surface" formula.

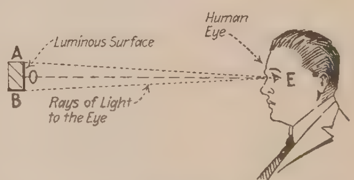


FIG. 52.—Illustrating the idea of brightness.

the roof and girder construction very dark in color and where the space is largely occupied with machinery of various sorts.

86. Brightness, although related to, should be carefully distinguished from illumination. Illumination applies specifically to the density of the light flux *impinging* on an illuminated object or an illuminated surface. Brightness relates specifically to the flux *issuing* from a light source or from some surface (Fig. 52) which is illuminated by a light source. There are two general methods of expressing the brightness of a surface which, although related, should be distinguished from each other. The terms used to designate these two methods are: (1) intrinsic brightness; and (2) surface brightness. It is desirable to apply the term *intrinsic brightness*

only to surfaces which actually generate light and to confine the use of the term *surface brightness* to surfaces which are visible only because of the light which they reflect. Intrinsic brightness in *candle-power per square inch* can, as will be shown, be easily reduced to Lamberts, the unit ordinarily used for surface brightness, and *vice versa.*

NOTE.*—In Fig. 53 a perfect diffusely reflecting surface, which is uniformly illuminated is viewed from position E through an opening in a screen. The surface is located successively in three positions A_1B_1, AB and A_2B_2. In all positions it appears of the same brightness. Its brightness is independent of inclination or distance from the eye. The brightness of a surface which is not a perfect diffuser may vary with

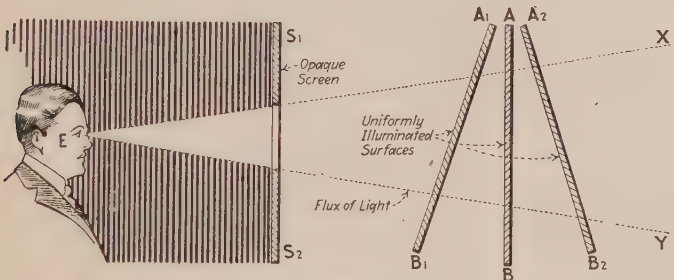


FIG. 53.—Diagram outlining the idea of brightness.

angle of view, but if it is large enough to cover the field of view, its apparent brightness will not vary with distance.

87. Intrinsic Brightness, or, as it is sometimes called, *intrinsic brilliancy,* is the apparent luminous intensity of a unit area of a luminous surface. It is usually expressed in apparent candle-power per square inch. The determination of intrinsic brightness is based† "on a luminous surface negligibly small in comparison with the distance to the observer." The general method of determining intrinsic brightness is illustrated by the following example:

EXAMPLE.—Assume that it is desired to determine the intrinsic brightness of the gas mantle M in Fig. 54. The apparent candle-power intensity of the luminous mantle in a direction XY, normal to the surface

* STANDARD HANDBOOK.

† A. I. E. E. STANDARDIZATION RULE 861. (July 1, 1915.)

of the mantle, would be ascertained by using a photometer, as illustrated. Assume that in the example shown, it is found that the apparent candle-power or luminous intensity of the mantle M in the direction XY, that is, the horizontal apparent luminous intensity, is 13.2 candles. In making this measurement the distance D "*should be great as compared with the dimensions of the mantle under test.*" D should be at least 10 or 15 times the greatest linear dimension of the mantle. Now, also assume that the mantle is, as shown at I, 3½ in. high and 1¼ in. in diameter, which would give a projected surface area of: $3.5 \times 1.25 =$ approximately 4.4 sq. in. Then the intrinsic brightness in candle-power per square inch of this mantle would be: $13.2 \div 4.4 =$ *3 c.p. per sq. in.*

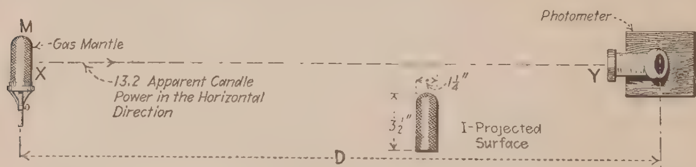


FIG. 54.—Illustrating method of determining intrinsic brightness.

88. Average Intrinsic Brightness or Intrinsic Brilliancy of Various Luminous Bodies.*—For a more complete table see the author's AMERICAN ELECTRICIANS' HANDBOOK.

Light source	Apparent candle-power per square inch	Light source	Apparent candle-power per square inch
Moore tube	0.3–1.75		
Candle	3–4	Tungsten, 1.0 watt per candle	950–1,050
Gas flame	3–8		
Oil lamp	3–8		
Cooper-Hewitt lamp	10–20	Sun, on horizon	2,000
Welsbach gas mantle	20–50	Flaming arc lamp	5,000
Enclosed a.-c. arc lamp	†75–200	Calcium light	5,000
Enclosed d.-c. arc lamp	†100–500	Open arc lamp	10,000–50,000
Incandescent lamps:			
Carbon, 3.1 watts per candle	450–500	Open arc crater	200,000
		Sun at zenith	600,000

89. The Reason Why It Is Desirable to Express Intrinsic Brightness in Candle-power per Square Inch is that the numbers involved would be awkwardly large if they were

*National Lamp Works of the General Electric Co. and other authorities.
†Surrounded by a diffusing globe.

expressed in Lamberts—although they could, as will be evident from a consideration of what follows (Art. 96), be expressed in this unit. Furthermore, it is desirable in order to avoid confusion, to express the brightness of light-generating surfaces in candle-power per square inch reserving the unit Lamberts for expressing the brightness of surfaces which are visible due only to diffuse reflection.

90. Luminous Sources of High Intrinsic Brightness Produce Glare.—Light-generating surfaces of an intrinsic brightness greater than 4 to 6 c.p. per sq. in. cause glare (Art. 222) effects which are often exceedingly pronounced and may be injurious. Almost any unshaded electric-light source will tire the muscles and retina of the eye (Art. 22) and prevent it from seeing objects clearly. Hence, it is well to avoid placing sources of light of greater intrinsic brightness than about 1 c.p. per sq. in. in the field of vision. Brilliant light sources in the line of vision should always be protected by frosted or translucent shades.

91. Surface Brightness should, as suggested above, be reserved as a term to designate the brightness of surfaces which are illuminated by light sources. Surface brightness, in Lamberts, is a measure of the density, at the surface, of the light flux reflected or issuing from it to the eye. Illumination in foot-candles is a measure of the density of the incident flux on the illuminated surface. Distinction between these two quantities can be readily appreciated if one considers the top of a table which, over its entire surface, is illuminated uniformly to a light flux density of 2 ft.-c. By this is meant that the number of flux lines per square foot, radiated to the top of the table by some light source, is the same over every portion of the table top. However, in spite of the fact that the illumination over the top of this table is uniform, common observation will show that a piece of white paper, 1 ft. square, laid on the top of the table will appear brighter to the eye than a piece of black felt, 1 ft. square. The reason for this is that, in spite of the fact that the number of flux lines impinging on the piece of felt is exactly the same as the number impinging on the piece of paper, the white paper is a better

reflector and directs more flux lines to the eye than does the felt. The idea is illustrated in an exaggerated way in Fig. 54*a*. A large number of flux lines from the light source L impinge on the surface SA, but, because this surface is a poor reflector, a relatively small amount of the incident flux is redirected by the surface.

92. The Lambert is the Unit of Brightness* and it is the brightness of a perfectly diffusing surface which is radiating or reflecting a lumen per square centimeter. For most purposes, the milli-Lambert (0.001 Lambert) is the preferable

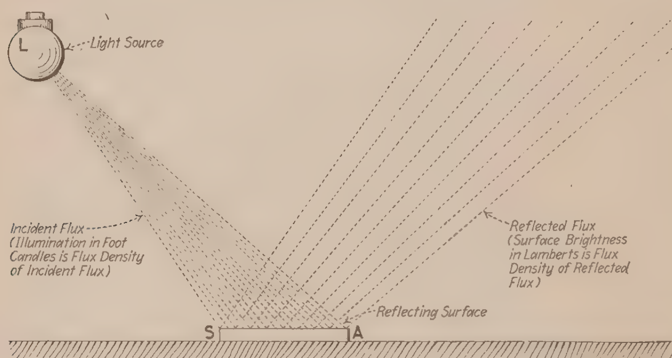


FIG. 54*a*.—Illustrating the ideas of illumination and of surface brightness.

practical unit. A perfectly diffusing surface emitting 1 lumen per sq. ft. will have a brightness of 1.076 milli-Lamberts.

93. The Working Equations for Brightness Computations are:

(30) $$L = \frac{F_r}{S} \qquad \text{(Lamberts)}$$

hence

(31) $$F_r = L \times S \qquad \text{(lumens)}$$

and

(32) $$S = \frac{F_r}{L} \qquad \text{(square foot)}$$

Wherein.—L = surface brightness of the surface illuminated, in Lamberts. F_r = total flux, in lumens, reflected by the surface. S = area of the surface, in square c. m.

*A. I. E. E. STANDARDIZATION RULE 863.

93A. In Practice* no Surface Obeys Exactly Lambert's Cosine Law of emission, hence the brightness of a surface in Lamberts is not generally numerically equal to its specific luminous radiation in lumens per square centimeter.

94. The Relation Between Illumination and Surface Brightness may be expressed by the following formula:

$$L = 0.929 \times E \times m \qquad \text{(milli-Lamberts)} \tag{33}$$

hence

$$E = \frac{L}{0.929 \times m} = \frac{L \times 1.076}{m} \qquad \text{(foot-candles)} \tag{34}$$

and

$$m = \frac{L}{0.929 \times E} = \frac{L \times 1.076}{E} \qquad \text{(coefficient of reflection)} \tag{35}$$

Wherein.—L = average surface brightness over the surface under consideration, in milli-Lamberts. E = the illumination incident on the surface, in foot-candles. m = the absolute coefficient of reflection of the material of the surface.

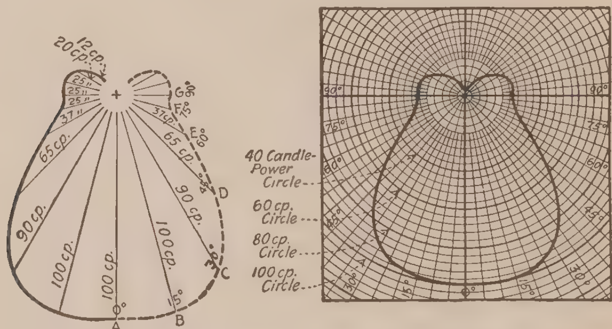
95. The Relation Between the Foot-candle and the Lambert can be explained thus: Both are units of light flux density. However, the foot-candle relates specifically to the density of flux incident or falling on a surface, whereas the Lambert or the milli-Lambert relates to the flux emanating from a surface. Although it is sometimes done, it is not proper to refer to the foot-candle brightness of a surface, because if the accepted definitions are followed, surface brightness cannot be measured in foot-candles but should be measured in Lamberts.

96. To Reduce Intrinsic Brightness in Candles per Square Inch to Lamberts, multiply the candles per square inch value by $\pi \div 6.45 = 3.1416 \div 6.45 = 0.4871$.

97. A Photometric Graph or Curve (Fig. 29) consists of lines plotted on a polar diagram which show graphically the distribution of the light flux in some given plane around an actual light source. It also shows the apparent candle-power intensities in various directions about the lamp or lamp and reflector. See Fig. 29 and other following illustrations for examples.

* A. I. E. E. Standardization Rule 865.

98. How to Read a Photometric Graph may be explained best by citing an actual example: In the photometric curve of Fig. 55, *I*, the apparent luminous intensity directly downward is indicated by measuring off this intensity on the vertical to a given scale. Thus, *XA* represents, in length, the candle-power in a vertical direction directly below the light. Similarly the distances *XB*, *XC*, *XD*, *XE*, *XF* and *XG* represent, respectively, apparent luminous intensities in all directions around the light at angles above the vertical of 15 deg., 30 deg., 45 deg., 60 deg., 75 deg. and 90 deg. Similarly, the apparent luminous intensities above 90 deg. can be scaled along the lines representing their respective angles.



I. Elementary Curve. II. Practical Working Curve.

FIG. 55.—Photometric graphs (or curves).

These points are then joined by a continuous line, *G*, *F*, *E*, *D*, etc., and this line, completed for the 360 deg., is called the photometric distribution graph or curve of the light. Fig. 55, *I* shows such a completed photometric curve, but in practice it is customary to use concentric circular lines (polar coördinates) as indicated on Fig. 55, *II*, to show the scale to which the candle-powers are plotted. The apparent candle-power intensities of the light unit can be measured along as few or as many angles as necessary, the accuracy of the resultant curve being largely determined by the number of angles taken.

99. The Area Within a Distribution Graph is Not Proportional to the Amount of Light Flux Lumens given off. Graph

B, Fig. 80, represents a smaller total flux, by an amount equal to the absorption in the reflector, than does curve A, though it has a larger area. A curve such as B is useful only for determining the apparent luminous intensity at any given angle below the horizontal.

100. A Line of Vision is a line drawn from a given point to an assumed natural position of the eye of an observer. When a lamp is concealed from the eye of an observer by a reflector, the lamp is out of the line of vision of the observer, but if the observer changes his position until he can see the lamp then it is in his line of vision.

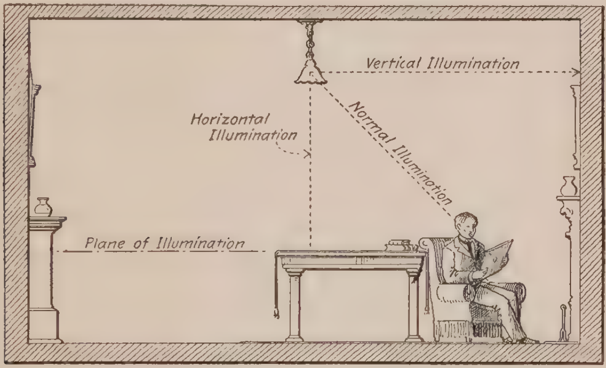


FIG. 56.—Illustrating horizontal, vertical and normal illumination.

101. A Plane of Illumination (Fig. 56) is some assumed or reference plane or surface where illumination is required, such as that including the tops of desks, tables or counters. An imaginary reference plane 30 in. above the floor is often assumed in practical work.

102. Normal Illumination (Fig. 56) is illumination received on a plane or surface which is normal or perpendicular to the rays of light perpendicular to the light flux.

103. Horizontal Illumination (Fig. 56) is the illumination on a plane or surface which is horizontal, such as on the top of a table, desk, floor, counter or the like.

104. Vertical Illumination (Fig. 56) is illumination received on a vertical plane such as a wall.

105. Uniform Illumination implies the lighting of an entire area with approximate uniformity. Streaks or shadows are undesirable because they are tiring to the eye. Highly polished reflectors that produce definite images of the light sources should, therefore, be avoided or used only with lamps which are provided with diffusing and enclosing globes, such as all-frosted incandescent lamps, arc lamps with opal inner globes, etc. Except in special cases, the illumination of an interior should be of a general nature (uniform illumination), that is, the whole interior should be evenly illuminated. This renders it possible to shift desks, tables, furniture, or machinery about without rearranging the lighting fixtures and wiring and without installing innumerable attachment circuits and extensions.

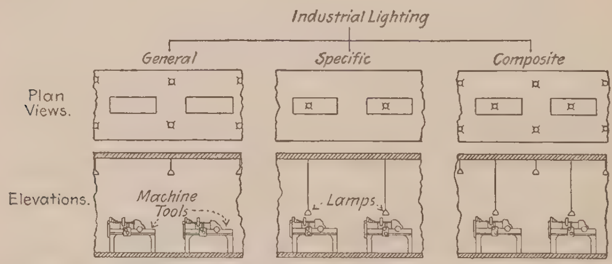


FIG. 57.—Illustrating general, specific and composite lighting. (Clewell.)

106. General Illumination (Fig. 57) is, then, as suggested above, that type of illumination wherein all portions of the given room or area are illuminated to approximately the same intensity.

107. Specific Illumination implies the brilliant lighting of certain specific areas in a room, which is otherwise less brilliantly lighted. Where a high density of illumination is required at one or two locations in a room that will otherwise permit of a rather low intensity, specific illumination is permissible for those locations. Where the light must come from a particular direction, as in delicate machine tool work, specific illumination is also permissible. Specific illumination usually involves more breakages, greater eye-strain, and in many cases misuse and, therefore, waste of light.

108. Localized Illumination is another name for specific illumination (Art. 107) which is the illumination of a certain relatively small area or of some particular object.

109. General, Specific and Composite Lighting* are defined graphically by Fig. 57, which shows installations of each of these types as applied to industrial lighting, but the definition applies with equal force to interior illuminations for any service.

110. All Lighting Systems Can in General be Classed Under One of Three Classifications† viz., direct, indirect and semi-indirect. In practically all lighting systems, some portion of the illumination is received indirectly. In *direct lighting*, when efficiency is important, it should be the aim to make the indirect portion of the illumination small, allowing only enough light to reach the ceiling and walls to illuminate them to a low intensity, thereby preventing a gloomy appearance. *Indirect illumination* is produced by the light being reflected from a very large area—the ceiling and upper portions of walls. This gives what is known as diffuseness of illumination. In such a system no direct light is received on the plane of utilization, the light source being concealed in an opaque unit.

What has been said in regard to indirect lighting applies equally well to *semi-indirect lighting* with this exception, viz., that the light source is mounted in a translucent rather than an opaque unit so that some of the illumination is received directly. Fig. 75 shows a semi-indirect lighting unit of one type. When properly designed, a semi-indirect system may possess all the illumination advantages of totally indirect lighting. It is attractive in appearance and eliminates the effect, considered unpleasant by some people, of a brilliant ceiling with no visible source of light. The danger in the use of semi-indirect lighting is that the translucent units will transmit too much light. When too much light is transmitted, the efficiency is rarely greater than with totally indirect lighting, and the illumination advantages of the indirect illumination are greatly reduced. Experience has shown that the best degree

* Clewell in INDUSTRIAL ILLUMINATION.

† H. W. Shalling, Ill. Eng. Soc., Pittsburgh, Jan. 24, 1913.

of transmission of light with semi-indirect units is possible *when the brilliancy of the light unit is approximately the same as the brilliancy of the ceiling.*

111. Direct Lighting is that wherein practically all of the light flux is radiated directly from the light source unit or units to the surface or objects to be illuminated. In direct lighting the flux is *not* first directed to the ceiling or other surface and then redirected to the things to be illuminated. Fig. 57 shows three examples of direct lighting.

112. Indirect Lighting is that form wherein the light source is entirely hidden and all of the light flux is first projected to the ceiling and walls from which it is then reflected downward and to the surfaces and objects to be illuminated.

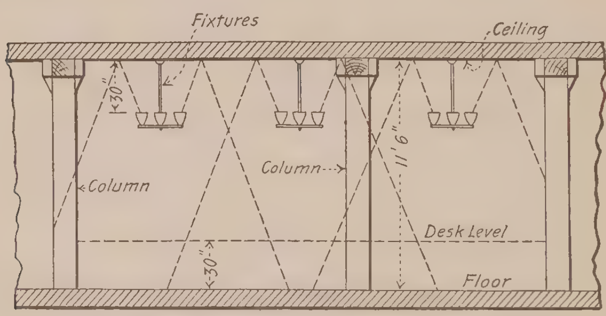


FIG. 58.—Example of indirect lighting.

113. In Indirect Lighting Installations* (Fig. 58) a reflector pointed upward, is placed under the lamp, and all of the light flux is directed to a light-colored ceiling. The room is illuminated by light reflected from the ceiling. The result is a widely diffused illumination which resembles daylight; that is, shadows and general effects are similar to diffused daylight coming through a skylight or window. The decoration of the room, especially of the ceiling in which the system is to be used, should be of some light color. For best results the ceiling should be a light cream or ivory, although somewhat darker shades give very satisfactory results. The walls of the room may be given darker tints, such as light brown,

* National X-Ray Reflector Co.

buff or tan. In all cases the lamps used with the system should be clear-bulb tungsten. Each lamp or group of lamps has its individual reflector, especially designed, thus insuring the highest possible efficiency.

114. Example of Indirect Lighting.—The light is reflected upward to a light-colored ceiling and thus diffused over the room. See Fig. 58. Special reflectors are preferable for this system. This extra cost is offset by the more pleasing effect obtained. Fig. 76 shows some typical fixtures for indirect lighting.

115. The Efficiency of an Electric Light Source was formerly given in *watts per candle*, which means watts per mean apparent horizontal candle-power. However, this method is unsatisfactory in that apparent horizontal candle-power (Art. 52) is not a true measure of the total light produced by the lamp. Furthermore, as the efficiency, on the above basis, increases, the figure expressing it decreases. A better method of expressing efficiency (Art. 68) is in *lumens per watt.*

116. Effect of Different Colored Lights on Various Colors.—

For Example: Red Light on a Black Surface Produces a Purplish-black Color, etc.

Original color	Red light	Orange light	Yellow light	Green light	Blue light	Violet light
Black	Purplish black	Deep maroon	Olive yellow	Greenish brown	Blue black	Faint violet black
White	Red	Orange	Light yellow	Green	Blue	Violet
Red	Intense red	Scarlet	Orange	Brown	Violet	Reddish violet
Orange	Orange red	Intense orange	Yellow orange	Faint greenish yellow	Violet brown	Light red
Yellow	Orange	Yellow orange	Orange yellow	Yellowish green	Green	Brown, faintly red
Light green	Reddish gray	Yellow green	Greenish yellow	Intense green	Blue green	Light purple
Deep green	Reddish black	Rusty green	Yellowish green	Deep intense green	Greenish blue	Bluish gray
Light blue	Violet	Orange gray	Yellowish green	Green blue	Vivid blue	Violet blue
Deep blue	Violet purple	Orange gray	Green slate	Blue green	Intense blue	Bright blue violet
Indigo blue	Purple, slightly violet	Orange maroon	Dull orange yellow	Dull green	Dark indigo blue	Deep blue violet
Violet	Purple	Red maroon	Yellow maroon	Bluish green brown	Deep bluish violet	Deep violet

SECTION 3

REFLECTORS

117. Reflection of Light is the redirecting of light rays by a reflecting surface. Whenever light energy strikes an opaque object or surface part is absorbed (Art. 125) by the surface and part is reflected. Light-colored surfaces reflect a larger part of the light thrown on them than do dark-colored surfaces, whereas dark surfaces absorb a larger part of the light. Black surfaces absorb nearly all the light which impinges on them.

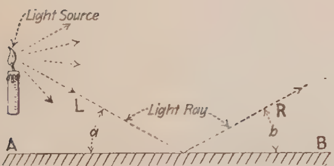


FIG. 59.—Reflection of light from a smooth surface.

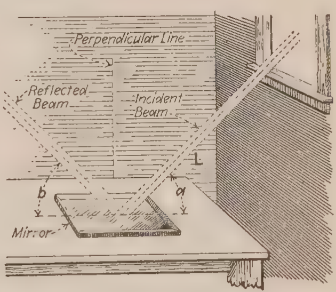


FIG. 60.—Angle of incidence equals angle of reflection.

EXAMPLE.—Consider first a smooth surface AB, Figs. 59 and 60, on which a ray of light L falls. This ray will be so reflected in the direction R, that the angle a is exactly equal to the angle b (Fig. 59). Consider now the effect of a number of rays falling on a smooth surface CD; see Fig. 61. Each ray will be reflected in such a way that it leaves the surface at the same angle at which it strikes it. The eye if held as shown would perceive only the light reflected into it.

Consider now a broken surface such as FG, Fig. 62. Each ray of light is reflected from that portion of the surface on which it falls just as though that point were on a smooth surface. The result is that the light is scattered, and if the surface is irregular enough, the eye placed at any point will receive reflections from many points of the surface. All

opaque surfaces except polished surfaces have innumerable minute irregularities like the surface in Fig. 62. This fact alone enables them to be seen.

118. The Phenomenon of Reflection in Terms of the Electron Theory may be explained thus. When a column of æther light waves impinges on an object the "light" due thereto is either *transmitted* through the object, *reflected* from the object or *absorbed* by it, depending on the nature and properties of the material comprising the object. However, all or a *part* of the light may be absorbed, reflected or transmitted.

If the object is of a material which is a good reflector, practically all of the light will be reflected, very little absorbed and possibly none transmitted. If the object is a good absorber, a piece of black cloth for example, practically all of

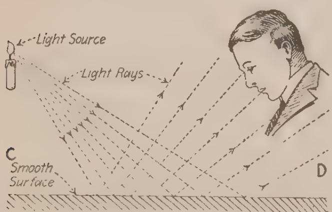


Fig. 61.—Reflection of light from a smooth surface.

Fig. 62.—Reflection of light from a broken surface.

the incident light will be absorbed and very little reflected and transmitted. If the object is a good transmitter—transparent—practically all of the light may, under certain conditions, be transmitted and very little reflected or absorbed. Some light must be reflected from every object which we see, otherwise we could not see the object.

The objects (luminous sources excepted) which we see about us, are, then, visible to us only for the reason that they reflect a portion of the æther waves which are originated by some luminous source. These waves then impinge on the objects from which they are "reflected" to the retinas of our eyes.

Every kind of matter—every sort of object—is composed of electrons (see the author's Practical Electricity) which,

for the most part, are revolving in circular orbits. When light impinges on the surface of an object, some or all of the incident æther waves are stopped by the matter—revolving electrons—at or near the surface of the object. If the material of which the surface of the object is composed is such that the electrons in the atoms comprising it are capable of rotating at such speeds that they can vibrate at the same rate as the impinging æther waves, then they do vibrate at that rate. Thereby, new trains of waves are generated by these vibrating electrons in the object and the light is then said to be reflected.

If light comprising æther waves of all visible frequencies—white light (Art. 14)—impinges on the object and there are electrons comprising the different atoms in the surface of the object which are capable of vibrating at all of these visible frequencies, then the light reflected by the object will be white light and the object will appear *white* to the eye.

If the electrons in the surface of an object are capable of vibrating only at some definite frequency, corresponding to the wave length or frequency of some particular color (Art. 14), then if white light impinges on that object, only light of that particular color will be reflected to the eye. It will then appear to be an object of that color. Thus, if the electrons in the atoms in the surface of a book cover are capable of vibrating only at the frequency corresponding to that of red light and white light impinges on the object the reflected light from that object will produce on the retina of the eye the *color sensation* of red. This sensation will be transmitted to the brain by the optic nerve and then the observer sees a red book cover.

If the light impinging on an object is not white light but is due to only the certain wave length corresponding to some certain color—red for example—when that light falls on an object it can stimulate in the surface of that object only those electrons which are capable of vibrating at the frequency corresponding to red light. Hence, if the surface of the object does contain electrons capable of vibrating at red-light frequency, the light reflected from it to the eye will be red light—or of a reddish hue. If the surface of the object does not

contain any electrons capable of vibrating at the red-light frequency, then none of the red-light rays can be reflected to the eye and the object will appear black.

Furthermore, to consider the illustrations further, if there are no red-light waves in the light impinging on an object, it is obvious that none of the electrons in the surface of that object can be made to vibrate at red-light frequency and no red light can be reflected from it. Thus, the red book cover referred to above, if viewed in the greenish light of a mercury-vapor lamp (the light from this lamp contains no red rays) will appear black.

The important thought in this electronic theory of reflection is that when the light waves from a luminous source impinge on an object, these waves are arrested by the electrons in the atoms of the object. However, the electrons in the surface of the object, may, under the conditions defined above, originate new trains of æther waves to the eye whereby the object becomes visible by "reflected" light. Reflection of light, probably, does not then involve the redirection of the original incident waves. It, so it is believed, involves the generation and transmission of new trains of æther waves to the retina of the human eye.

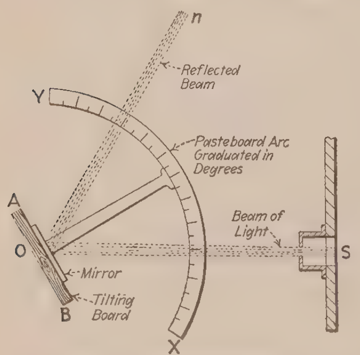


FIG. 63.—Arrangement for proving that the angle of incidence equals the angle of reflection.

119. The Angle of Incidence is Equal to the Angle of Reflection and the two angles lie in the same plane. This is merely another way of stating the fact brought out in the preceding paragraph in reference to Fig. 59. This is a very important fact.

EXAMPLE.—Arrange a board *AB*, Fig. 63, in a darkened room so that it may be rotated around a center *O*. Mount a mirror on this board and place the device so that a beam of light admitted through a slot *S* will impinge on the mirror. Then if the mirror be worked into different posi-

tions it will be found that the angle of incidence X always equals the angle of reflection Y. An arc cut from the pasteboard, on which degree graduations have been indicated in pencil, mounted just back of the beam will assist the observer in verifying the angles.

120. Regular Reflection is that received from a surface which directs the light at regular angles.

121. Irregular Reflection is that received from a medium having an irregular surface which projects the reflected rays in many different directions as shown in Fig. 62.

122. Reflecting Power of Surfaces.—Different surfaces reflect different percentages of the light falling upon them. The illumination of a small room having poorly reflecting walls can often be improved by changing the wall coverings, particularly if bare lamps are used. If the room is large or if reflectors are used to throw the light downward so that not much light reaches the walls to be reflected, a change in the wall covering will have little effect on the general illumination.

123. A Coefficient of Reflection is a factor or percentage value indicating the ratio of the intensity *of a ray of light that is reflected* from a reflecting surface to the intensity *of the ray that strikes the surface*. See Table 124. The symbol m* is ordinarily used to designate a coefficient of reflection.

124. The Following Table of Reflection Coefficients† is useful in showing the relative reflective value of wall coverings in rooms. For a more complete table see the author's American Electricians' Handbook.

Material	Per cent. reflection	Material	Per cent. reflection
Highly polished silver.....	92	Chrome yellow paper....	62
Optical mirrors silvered....	70 to 85	Light pink paper.......	36
Highly polished brass.....	70 to 75	Dark brown paper......	13
Polished gold.............	50 to 55	Blue-green paper.......	12
White blotting paper......	82	Deep chocolate paper...	4
White cartridge paper.....	80	Black velvet...........	0.4

*A. I. E. E. Standardization Rule 895.

† Art of Illumination, Bell.

125. Absorption is the loss of intensity or of volume of light that occurs when the light passes through a translucent material, or when it is reflected by a reflecting surface.

126. A Coefficient of Absorption is the ratio of (*the difference between the intensity of the transmitted ray and the intensity of the incident ray*) to (*the intensity of the incident ray*) expressed as a percentage of the incident ray.

127. Absorption of Light by Globes and Reflectors.—If globes are used on lamps, account must be taken of the light absorbed by the globes in calculating the effective illumination in the room. Table 128 gives average values of the proportion or percentage of the light which is absorbed in passing through globes made of different kinds of glass.

128. Coefficients (Per Cent.) of Absorption of Globes and Shades.—See the author's American Electricians' Handbook for a more complete table.

Material	Per cent. absorption	Material	Per cent. absorption
Clear glass globes........	5 to 12	Heavy opalescent globes	30 to 60
Light sand blasted globes..	10 to 20	Flame glass globes.....	30 to 60
Ribbed glass globes.......	15 to 30	Ruby glass globes.......	85 to 90
Ground glass globes......	20 to 30	Cobalt blue globes.....	90 to 95

129. Refraction (Fig. 64) is the changing from the straight line (which a light ray normally assumes, Art. 19) that occurs when the ray passes from one medium into another of different density.

Example.—When the ray from the candle of Fig. 64 impinges on the glass G_1G_2, it does not pass through the glass in the straight line SQ but is *refracted* and assumes the direction XY. Again, in passing out of the glass, it does not follow the straight line XP but is again refracted into the direction YZ. Air and glass have different densities, hence the refraction effects just noted. Different materials have different refractive effects, that is, different *Indices of Refraction.*

130. An Unshaded Incandescent Lamp should never be tolerated under any circumstances, unless the bulb is completely frosted, and even then only in such locations as store

rooms, etc., where it is desirable to light the entire wall surface, and where the eyes are normally directed away from the location of the lamps. This is because the lamp filament has a high intrinsic brilliancy; hence, looking at it continually with the unprotected eye is apt to permanently injure the eye.

131. Shades, Globes and Reflectors.—Reflectors are used in general to reflect light (that would otherwise pass off in some useless direction) to a direction where it will be useful. Shades are used to protect the eye from light sources that would otherwise be in the line of vision. See Art. 100. Globes are used generally for artistic reasons, but some types of globes can be used for the same purpose as reflectors: to direct light to a useful direction. Reflectors are also used largely for artistic purposes. In selecting artistic globes and reflectors, those should, in general, be chosen which produce the best illumination where it is desired.

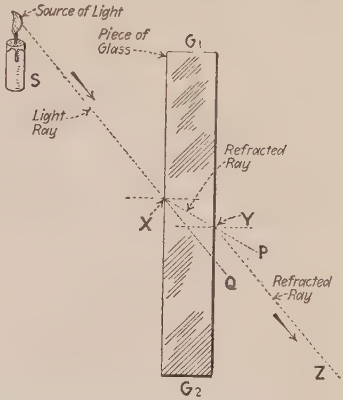


FIG. 64.—Illustrating refraction.

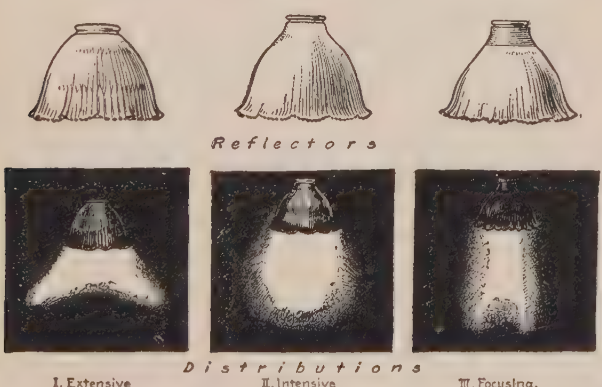


FIG. 65.—Typical prismatic glass reflectors.

132. Prismatic Glass Reflectors (Fig. 65) depend for their effectiveness upon the physical law *that when a ray of light strikes upon a surface of clear glass at less than a certain angle (usually below* 30 *deg.) it will not pass beyond the surface, but will be reflected.* The Holophane* are prismatic glass reflectors. The surfaces of the prisms of prismatic reflectors are so calculated that most of the rays from a lamp correctly located within the reflector will strike the surface of the prism at less than the critical angle, and will be reflected in a useful direction, Figs. 66 and 67. This is the most efficient type of reflector known, excepting a silvered mirror. Very little light is absorbed

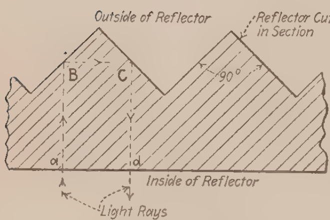


Fig. 66.

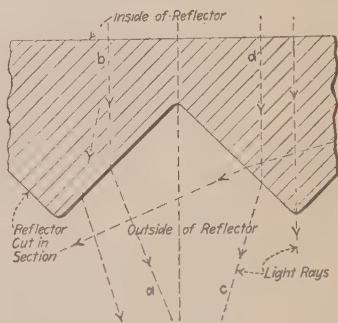


Fig. 67.

Fig. 66.—Enlarged view of prism of prismatic reflector.
Fig. 67.—Cross-section of prismatic reflector, showing how light rays are refracted and dispersed.

by the reflector. The small percentage that is not reflected is largely transmitted, allowing sufficient light to reach the upper walls and ceiling to lend a cheerful appearance to the rooms. Owing to the high efficiency, the light from the inside of the reflectors is rather glaring. If the bowl-shaped reflectors, now universally used, are properly located, it is impossible to see into the inside of the unit except by looking up at an unnatural angle. Where greater softness is desired it may be attained by the use of satin-finish reflectors, which are very lightly ground on the inside surface, thus breaking up the sharp reflections without materially reducing the efficiency. These

* Holophane Company.

reflectors are quite generally used with tungsten lamps for store, office and factory lighting where high efficiency is desired.

133. The Theory of Prismatic Glass Reflectors.*—The inner surface of the reflectors is smooth or lightly ground, as described above. The outer surface is formed into vertical prisms which act by total reflection. The rays from the lamp penetrate the inner surface of the reflector and are thrown back from the outer surface in the manner indicated in Fig. 66. Since the contour of the reflector as well as the design of the prism determines, to a large extent, the distribution obtained, it is possible to redirect the light in almost any desired direction. The design based on the principle of reflection from the exterior prisms involves a much more complex calculation than would be the case if the phenomenon of reflection occurred only in the simple manner indicated in Fig. 66. The reflectors diffuse the light as indicated in Fig. 67, some of the rays striking the prisms at such angles that some of the light is not reflected but refracted, and passes through the outer surface of the glass. Other rays strike the apex of a prism, which, owing to mechanical limitations, is slightly rounding, and such rays emerge from the glass. Similarly in the valleys between the prisms a small portion of the light is transmitted instead of being reflected. Therefore, observing a Holophane reflector from the outside, since there is a large number of rays being transmitted in this diffused manner, it appears to the eye that light is emitted from practically the entire surface. The result of the diffusion is that the outline of the light source is lost entirely and the high intrinsic brilliancy of the lamp filament is reduced to low values which the eye can endure without strain or fatigue. Holophane reflectors in general give one of five characteristic distributions of light—extensive, intensive, focussing, concentrating or asymmetric, which are described in Art. 146 and succeeding articles.

134. Alba Glass Reflectors (Fig. 68) are made of a heavy milky-white glass produced by mechanically intermingling with clear glass a multitude of minute opaque reflecting par-

* Holophane Company.

ticles. The manufacturers claim a high degree of reflection and diffusion, with very small absorption, and no change in the color of the light reflected. These reflectors are also quite widely used for store, office and factory lighting, and are popular for residence use. They are also well adapted for semi-indirect systems.

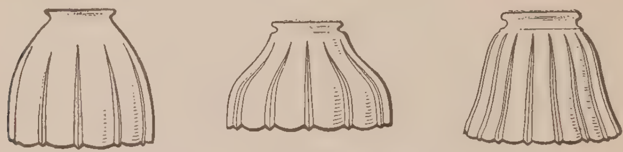


FIG. 68.—Alba glass reflectors.

135. Ground-glass Globes and Shades are suitable only for shading and diffusing the light, being subject to the same limitations as opal glass, with the additional disadvantage that they get dirty very quickly and are difficult to clean.

136. Opal Glass is a colored glass of widely varying characteristics, depending on the maker. If the color is light

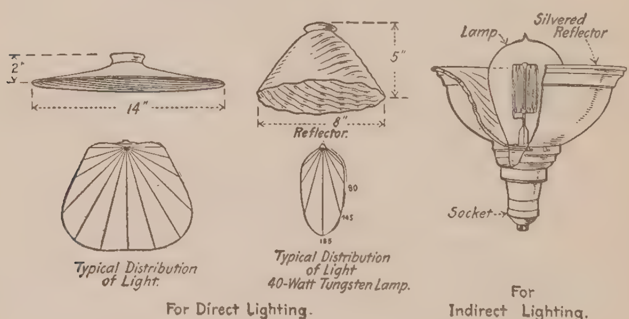


FIG. 69.—Mirrored reflectors.

enough not to absorb the light, the diffusion is poor. If the color is deep enough to give good diffusion, and hence properly serve as a shade, a large amount of the light is absorbed. Shades of this material are not usually good reflectors for direct lighting and their use is restricted to locations where ornamentation is of more importance than efficiency. How-

ever, they may often be utilized to advantage in semi-indirect lighting installations.

137. Mirrored Reflectors (Fig. 69) are most satisfactory for indirect systems and for show-window lighting, the lighting of pictures, etc. A plane-mirrored surface is unsatisfactory on account of the reflections from the filaments, which caúse striations or streaks in the lighting. Various types of corrugated surfaces (Fig. 70) are used by different manufacturers to overcome this effect, and many of the designs are highly efficient. Reflectors of this type are not used as widely for general illumination as are those of transparent or translucent glass, because with a mirrored reflector arranged for downward distribution, no light is thrown above the horizontal.

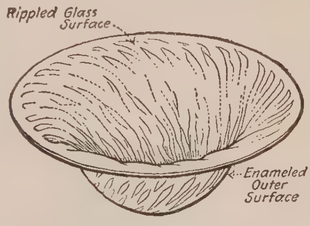


FIG. 70.—Silvered reflector for indirect lighting.

138. One Make of Silvered Glass Reflector is Called the "X-Ray."—The body of the reflector is of clear glass in one piece which is silvered on its outer surface with a sterling silver preparation, and then coated with a green elastic enamel. This enamel protects the silvering, thus preserving the efficiency of the reflector. To eliminate streaks and to assist in the diffusion of the light, the glass is blown with spiral and vertical corrugations.

FIG. 71.—Typical enameled steel reflectors.

139. Metal Shades and Reflectors (Figs. 71 and 72) are useful principally for show-window and show-case illumination and in manufacturing establishments, where rough usage would prevent the installation of any other type. A polished metal surface is intolerable, but the so-called aluminum finish is fairly efficient, and produces excellent diffusion.

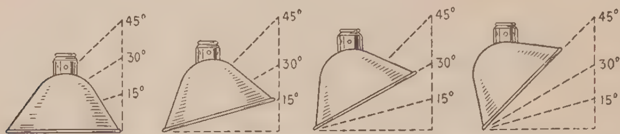


FIG. 72.—Metal reflectors arranged to throw light at different angles especially designed for localized lighting around machinery.

140. Interiors of Common Metal Shades and Reflectors Can Be Painted with Aluminum Paint when they become dirty. The matt aluminum reflecting surface produces a reflected light without streaks. It is often quite as cheap and usually much more effective to thus paint the interiors of many kinds of reflectors than to endeavor to clean them.

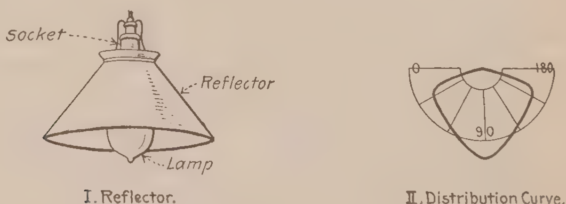


FIG. 73.—Painted sheet-metal reflector.

141. Reflecting Shades* are made of all sorts of material —paper, metal polished, painted or enameled, porcelain and glass of many kinds. Perhaps the simplest example of this class is that shown in Fig. 73, *I*, an 8-in. cone often painted green on the outside and white on the inside. Fig. 73, *II*, gives the distribution of light resulting from its use, the reference circle showing the angles of distribution. A modification is shown in the McCreary shade, Fig. 74, *I*, a narrow 7-in. reflecting cone with a diffusing screen below, from which the

* Bell's ART OF ILLUMINATION.

distribution is shown in Fig. 74, *II*. It is of an angle narrow compared to the simpler form, and softens the light very materially. The data from these shades are as shown in the following Table 142, the lamps in each case being 16 c.p.

Reflectors such as referred to in Table 142 are seldom used for general illumination, but often over desks and work tables. A later and very excellent shade for such use is a 10-in. porcelain cone resembling Fig. 73 in shape, and like it green outside and white inside, but slightly translucent. These varied slightly in dimensions and angle are admirably adapted for use at desks and in reading rooms. It is best to use them with frosted bulbs if their location is such that the white reflecting interior is visible to the eye when reading, as its brilliancy is too considerable to be comfortably endured otherwise.

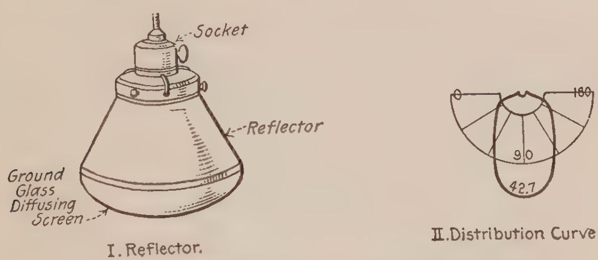


FIG. 74.—Glass reflector with diffusing screen.

142. Characteristic Data for Simple Reflectors.*—

	Plain cone	McCreary
Mean spherical candle-power	8.12	7.50
Maximum apparent candle-power	29.49	42.72
Horizontal apparent candle-power	0.00	2.29
Absorption per cent	28.10	33.50

143. Reflectors Should be Kept Clean.—All reflectors decrease greatly in efficiency when allowed to become dirty. In factories, sufficient illumination is ordinarily lost in 10 to 20 days, on an average, to more than pay for the cost of cleaning.

* Bell in STANDARD HANDBOOK.

144. Reflectors for Semi-indirect Lighting are manufactured in a variety of designs. One type is shown in Fig. 75 and there are others illustrated on other pages.

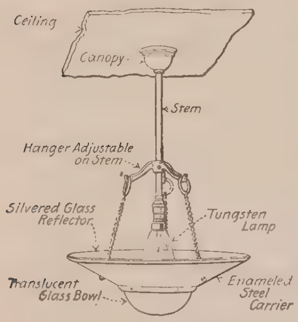


FIG. 75.—Semi-indirect lighting fixture with glass bowl bottom. (I. P. Frink Co.)

145. For Reflectors for Indirect Lighting.—Many different types are used, each adapted to particular conditions. One of these, a distributing type of reflector, is illustrated in Fig. 69. Before attempting to suggest fixtures for any particular interior it is well to determine exactly what the conditions are under which the system is to be used, since the size and height of the room, color of walls and ceilings, as well as the location of the electric outlets, all affect the style of equipment which should be specified. Styles of fixtures employed with this system are shown in Fig. 76. These fixtures are installed in exactly the same way as other electric-lighting fixtures. Some are de-

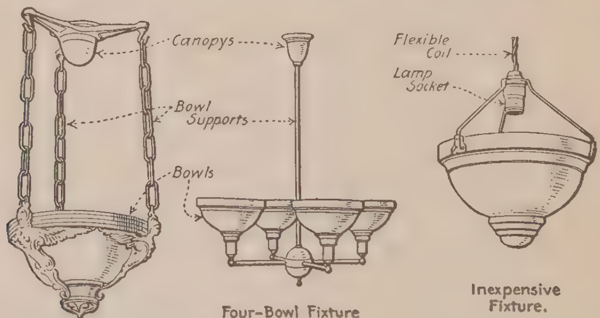


FIG. 76.—Examples of fixtures for indirect lighting.

signed for single lamps, others for multiple units, some types are made of metal, while others are constructed of "Compone" and composition. Special adaptables which may be added to the ordinary arm fixture can be procured. These adaptables

hold the reflector in the correct relation to the filament of the lamp and can be readily fitted to arm fixtures that are already in place.

146. Extensive, Intensive and Concentrating Reflectors (Fig. 65).—The Holophane Company first classified its reflectors into extensive, intensive and concentrating types, to which was later added the focussing type, the name designating the broadness of distribution as indicated by the distribution curve. These type names have since been adopted by other reflector manufacturers who make reflectors having definite and in general somewhat similar distribution curves, adapted for different mounting heights and spacing distances.

147. Extensive Globes and Reflectors (Fig. 65, *I*) distribute the reflected light over a wide angle below the horizontal. See Fig. 77. They are primarily for lighting moderately small rooms (say 12 ft. square) with single units or chandeliers on which the lamps hang pendant. The "extensive" type of distribution will meet the requirements of the following classes of rooms.*

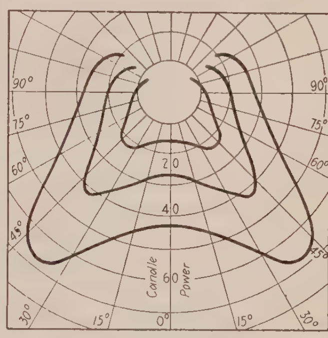


Fig. 77.—Typical photometric curves of lamps with "extensive" reflectors.

1. Rooms in residences where a single light or group of lights centrally located is employed (the distribution of several units hung vertically being approximately the same as that of a single unit).

2. Small offices, waiting rooms, alcoves, etc., where the conditions are substantially as above.

3. Wide hallways having moderate height of ceiling, stockrooms, workrooms or other cases where even, general illumination is desired from a single line of outlets.

Extensive reflectors of the Holophane line give a distribution with the maximum candle-power at about 45 to 50 deg. up from the vertical.

* National Electric Lamp Association.

148. Intensive Globes and Reflectors (Fig. 65, *II*) throw the light downward in a rather narrow angle. See Fig. 78. The primary purpose for which the "intensive" type of distribution was designed is that of evenly illuminating large rooms by means of distributed units placed close to the ceiling in the form of squares. This system is used commonly in department and other large stores, in dining halls and restaurants, hotel and club lobbies, large offices, assembly rooms, lodge rooms, halls of moderate dimensions, council chambers, court rooms, etc., where the lights are hung high above the plane of illumination. This method of lighting is seldom used in residences. Intensive reflectors of the Holophane type have their maximum candle-power below 45 deg.

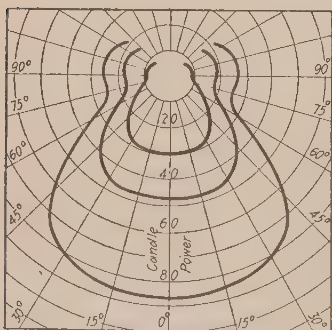


Fig. 78.—Typical photometric curves of lamps with "intensive" reflectors.

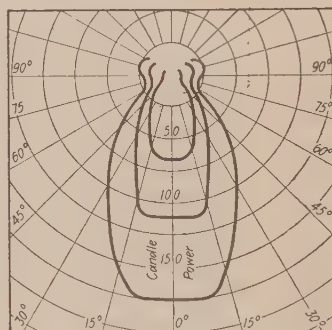


Fig. 79.—Typical photometric curves of lamps with "focussing" reflectors.

149. Focussing Globes and Reflectors (Fig. 65, *III*) concentrate the light to a small area, producing greatest intensity of illumination along the vertical axis of the reflector. See Fig. 79. The classes of lighting for which "focussing" reflectors are designed, include the illumination of tables, desks, display windows, store counters (by means of a row of lights placed high and directly over the same) and very high rooms (where they are used in the same manner as the "intensive" type). "Focussing" reflectors give an end-on candle-power approximately three and one-half times as great as the lamp's rated

horizontal candle-power. The area intensely illuminated is a circle, the diameter of which should be one-half the height of the lamp above the plane of illumination; outside this limit the intensity falls rapidly, but not so abruptly as to give the effect of a spot of light. Holophane "focussing" reflectors give their maximum candle-powers at about 10 deg. from the vertical.

150. Concentrating Reflectors throw the light more strongly downward than those of the focussing type, giving in some cases a vertical end-on candle-power of eight times the rated horizontal candle-power of the bare lamp. Higher concentration can easily be obtained but is not generally required commercially.

151. Application of Extensive, Intensive, Focussing and Concentrating Reflectors.—In general (see Art. 233 for further more-definite information), focussing reflectors should be used when the distance between lamps is three-fourths the mounting height; intensive reflectors should be used where the distance between lamps is about one and one-fourth times the mounting height; extensive reflectors should be used where the distance between lamps is twice the mounting height. These values are averages and may not apply to all makes of reflectors. If the best results as to uniformity of illumination are desired, lamps should be suspended from ceilings at such a distance as to give proper ratio of lamp spacing to mounting height (Art. 240) as advised by the reflector manufacturer or as determined by plotting illumination curves. The different types (extensive, intensive, etc.) of reflectors are not, in general, designed to give different illumination results. They are designed to give the same result, each type being suitable for a different condition of height and spacing of lamps.

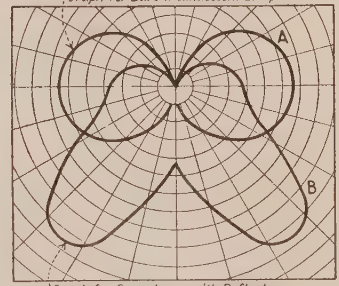


FIG. 80.—Comparison between distribution curve of a bare incandescent lamp with that of the same lamp equipped with a suitable reflector.

152. Asymmetric Reflectors (see also Art. 330) are those by which most of the light rays are thrown toward one side of the reflector. This is effected by interior vertical prisms which redirect the light from the side where it is not needed.

153. Distribution Curves of Reflectors.—The effect of a reflector in changing the direction of light given out by a light source is best expressed in the form of a distribution curve. Fig. 80 shows such a graph for a bare lamp and for the same lamp with a reflector. The graph represents the light in a single vertical plane through the center of the light unit, and it is assumed that the light in all similar vertical planes is similarly distributed. See Art. 98 "How to Read a Photometric Curve."

SECTION 4

INCANDESCENT LAMPS

154. Electric Incandescent Lamps (Fig. 81) consist of a filament, which is a highly refractory conductor, mounted in a transparent glass bulb and provided with a suitable electrically-connecting base. In incandescent lamps of the older types the air was, in so far as practicable, exhausted from the space within the bulb and surrounding the conductor (filament), leaving there a vacuum. But in many of the modern lamps this space is filled with an inert transparent gas—nitrogen, for

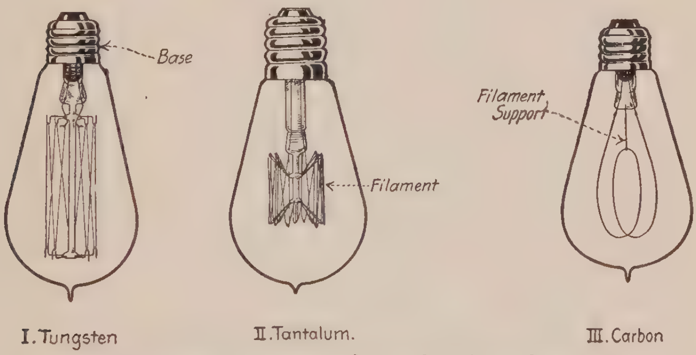


Fig. 81.—Tungsten, carbon, and tantalum incandescent lamps.

example. The filament conductor must have a high melting point or high vaporizing temperature and a high resistance; it must be hard and not become plastic when heated. In "vacuum-type" lamps the vacuum must be good, not only to prevent the oxidation of the filament, but also to prevent the loss of heat, which would reduce the efficiency. In non-vacuum-type lamps (gas-filled lamps) the gas used must be inert so as not to combine chemically with the filament material. The bulb must be transparent to permit the passage of light, not

porous, so that it will retain the vacuum or inert gas, and strong to withstand handling and use.

155. Classes or Types of Incandescent Lamps.—There are now but three classes of incandescent lamps on the market, viz.: (1) *Carbon*-filament, (2) *Metalized*-filament or Gem, and (3) *Tungsten*-filament or "Mazda." Several years ago the *tantalum* lamp was quite popular because it was then economical; this was prior to the perfection of the tungsten lamp. The demand for and manufacture of tantalum lamps has practically ceased because of the materially higher efficiency of the tungsten (or Mazda) lamp. Each of the types is described below.

156. The Carbon-filament Incandescent Lamp,* in fact, the first commercial incandescent lamp, was introduced by Thomas A. Edison in 1879. Its filament was horseshoe-shaped and made of carbonized paper. It had an efficiency of about 7 watts per candle, which was later raised to 4.8 watts per candle when the carbonized-bamboo filament was adopted. This improvement increased the total life of the lamp, but the candle-power performance was poor, declining approximately 20 per cent. in the first 100 hr. Further improvement in 1881 brought the efficiency up to 4.6 watts per candle. In the manufacture of the present carbon filament, absorbent cotton is dissolved in zinc chloride solution, forming a thick viscous liquid which is forced, under pressure, through a die. Thus, a long thread-like filament is formed. This is then dried, shaped and afterward carbonized. The efficiency of the present carbon-filament incandescent lamp is, approximately, 3.0 watts per candle with a useful life of 450 hr.

Since the introduction of the much-higher-efficiency tungsten lamps the demand for carbon lamps has decreased to practically no demand at all. "Carbon" lamps were originally made in a variety of sizes from 2 to 50 c.p. and in different shaped bulbs. But at present the only carbon lamps for which there is any demand are the 10- and 20-watt sign lamps, the 20-, 30-, 50- and 60-watt regular lamps for 105 to 125-volt

* Handbook of Incandescent Lamp Illumination, Edison Lamp Works of the General Electric Co.

lighting circuits and 35- and 60-watt lamps for 220 to 250-volt circuits.

157. The Effect of Voltage Variation on Carbon-filament Incandescent Lamps.—Slight variations in the voltage impressed on any incandescent lamp result in considerable variations in its light production and in its useful life (Fig. 82, *I*). Thus, for a carbon-filament incandescent lamp, if the lamp is operated at a voltage 1 per cent. greater than that for which it was designed, its apparent candle-power will be increased by about 6 per cent. and its life will be decreased by approximately 20 per cent. If operated on a voltage 1 per cent. lower than that for which it was designed, its apparent candle-power will be decreased by about 5 per cent. and its life increased by

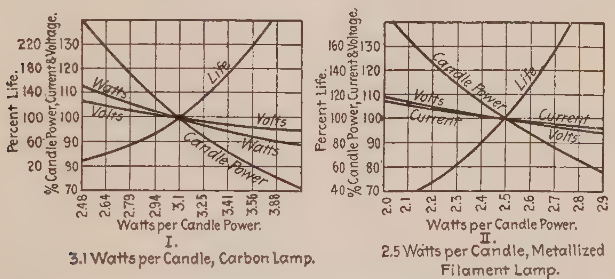


FIG. 82.—Approximate characteristic curves of carbon and metalized filament lamps.

approximately 20 per cent. For a table in which are shown percentage values indicating over a wide range the effects of different percentages of voltage variation, see the author's AMERICAN ELECTRICIANS' HANDBOOK.

158. The Metalized Filament Lamp is similar to the carbon lamp, except that the filament, after flashing, is still further modified by a graphitizing process in an electric furnace. This treatment renders the filament more refractory so that it may be worked at a higher temperature with the same life, thus securing a higher efficiency. The temperature characteristic is changed from negative to positive, whence the name of the lamp, which merely means that the character of the carbon filament has been changed until it acts like a metal filament.

The lamp is, therefore, not as sensitive to voltage changes as the ordinary carbon filament. These lamps do not "blacken" as early in life or to the same degree as do carbon-filament lamps.

159. As to the Effects of Voltage Variation, with the Metalized Lamp (Fig. 82, *II*), 1 per cent. decrease in voltage decreases the watts approximately 1.8 per cent., decreases the candle-power about 4.8 per cent., increases the watts per candle about 3 per cent. and increases the life about 18 per cent.; 1 per cent. increase in voltage increases the watts about 1.8 per cent., the candle-power about 4.4 per cent., decreases the watts per candle about 2.4 per cent. and the life about 14 per cent. A table is given in the author's AMERICAN ELECTRICIANS' HANDBOOK showing numerically the effects, over a considerable range, of variations in the applied voltage.

160. Efficiency of Carbon and Metalized-filament Incandescent Lamps.—Almost any reasonable efficiency of carbon or metalized-filament lamps can be obtained, with corresponding variations in life. All modern lamps, except street series lamps, are rated by their watts consumption only, the old rating by candle-power was illogical and frequently caused confusion.

161. The Tantalum Lamp had a filament composed of metallic tantalum. It had an efficiency of about 2 watts per candle. This lamp is not satisfactory for use on alternating current as the filament becomes beady and breaks after a short life. The demand for this lamp has practically ceased, it having been superseded by the more efficient and rugged tungsten lamp.

162. Tungsten or Mazda Lamps.—The filament of the tungsten lamp is composed of pure metallic tungsten. When the lamps were first manufactured, the finely divided metal was mixed with a binder and squirted through a die, the binder afterward being burned away. As so made, the filaments were hairpin shape, and a number of them were connected in series in each lamp. At present the metal is drawn through dies, the same as any other wire, the final drawings being through diamond dies. The filament has a high tensile strength, is quite elastic and reasonably flexible. The filament in each lamp is continuous, producing much better effi-

ciency and greatly improved life. The modern lamps are capable of standing the abuse that may be accorded carbon or metalized lamps, and are very greatly superior to those originally produced, standing any reasonable amount of vibration without breakage. Unless accidentally broken, the lamps will easily average 1,000 hr. useful life. In fact, the efficiency ratings have been increased repeatedly (*i.e.*, the watts per candle decreased) in order to keep the average lamp from exceeding the rated life too greatly. The useful life of vacuum lamps has also been greatly increased by the addition of certain elements which absolutely prevent, except in case of impaired vacuum, the blackening of the globes, which was formerly so common.

It is possible to substitute tungsten lamps for either the obsolete carbon or the metalized-filament lamps to give an equivalent candle-power with a saving of at least 60 per cent. in the energy consumed, or to consume an equivalent amount of energy with an increase of at least 60 per cent. in the light produced. The saving effected by the use of tungsten lamps, especially by substituting the larger-size lamps for many smaller lamps, is of great importance.

The efficiencies of modern vacuum tungsten lamps range from about 1.3 watts per candle for the 10-watt lamps up to 0.9 watt per candle for the 250-watt lamps. The average for all sizes is about 1.3 or 1.4 watts per candle.

163. Color of Light from Tungsten Lamps.—Owing to the extremely high melting point of tungsten (about 3,100°C.) it is possible to work the tungsten filament at a much higher temperature than any other known filament material. This produces the high efficiency of the lamp, and also gives a light which is nearly white in color, more nearly approaching sunlight than any other of the common artificial illuminants.

164. Gas-filled, Tungsten Incandescent Lamps.—Until recently it has been the practice of lamp manufacturers to exhaust the bulbs of incandescent lamps to an almost perfect vacuum. It has, however, been demonstrated that it is possible to operate tungsten wire filaments at higher temperatures in a bulb containing an inert gas. The presence of this inert

gas in the bulb retards the evaporation of the filament. The convection currents—hot-gas currents—carry any particles evaporated to the upper portion of the bulb where they are deposited but where they absorb very little useful light. The filaments of these lamps are coiled and mounted in a compact manner to prevent their being cooled appreciably by the passage of the rising gas. These gas-filled tungsten lamps are referred to by some manufacturers as *Mazda C* lamps to distinguish them from the vacuum tungsten lamps which are now called *Mazda B*. The gas-filled lamps operate at considerably higher efficiencies than do the vacuum lamps but are so designed as to give the same useful life, viz., 1,000 hr. It is the usual practice to make the gas-filled lamps with pear-shaped bulbs having long glass necks. The efficiencies range from 0.80 watt per candle for the 100-watt multiple lamp to 0.45 watt per candle for the 1,000-c.p., 450-watt street series lamp.

165. Gas-filled Series Tungsten Lamps are now being used in large numbers for street lighting. In order to adapt them for use in series with arc lamps on regular series circuits, they are manufactured in the same ampere capacities as standard arc lamps. The same size filament is used in all lamps of the same current rating, the change in wattage and candle-power being secured by changing the length of the filament. The voltage of the lamps, therefore, varies with the size, being greatest in the large lamps. The performance characteristics are given in a table in the author's American Electricians' Handbook which is revised frequently in an endeavor to keep it abreast of the improvements being made constantly by the incandescent-lamp manufacturers.

166. Tungsten-lamp Characteristics.—The positive temperature characteristic of the metalic filament renders the tungsten lamp much less sensitive to voltage variation than the carbon or even the metalized-carbon filament lamps. The resistance of the filament is very much lower when cold than at its operating temperature. This permits it to take an abnormal current when first connected in circuit, causing the light intensity to increase very rapidly, producing the well-known "overshooting" of tungsten lamps. This is

especially noticeable when both carbon and tungsten lamps are controlled from the same switch, the white light from the tungsten lamps appearing an appreciable interval of time before the yellower light of the carbon lamps. The changes produced by this characteristic of the tungsten lamp by changes in voltage are given in 159.

167. The Effect of Variations of Voltage on Tungsten-filament Incandescent Lamps is not so pronounced as with carbon and metalized-filament lamps as outlined above. When one of these lamps is operated at a voltage 1 per cent. above its rated voltage, its life is decreased by about 14 per cent. and its apparent candle-power is increased by about 3.5 per cent. See the range of values tabulated in the author's AMERICAN ELECTRICIANS' HANDBOOK for further detailed information on this subject.

168. Illumination Data on Tungsten-filament Incandescent Lamps is also tabulated in the author's AMERICAN ELECTRICIANS' HANDBOOK. The art of incandescent-lamp manufacture is now advancing so rapidly that it is impracticable to maintain these data up to date in any book which is not revised very frequently. THE AMERICAN ELECTRICIANS' HANDBOOK is revised frequently. Hence it appears desirable to print in it such data as is most subject to change. The efficiencies of tungsten lamps have been increased repeatedly by the lamp manufacturers during the past few years. In the tables referred to, the *Efficiencies, Candle-powers, Lumens Output* and *Reduction Factors* for lamps of the different wattages and voltages are given.

169. Voltage and Wattage Ratings of Incandescent Lamps.—All incandescent lamps for standard lighting circuits are now rated in watts. The watts rating of every lamp is indicated on its label. On the label is also specified the voltage at which the lamp is designed to operate. *The Three-Voltage-Rating* was formerly used, but the present practice is to show only one voltage. During the pioneer days of tungsten lamps their performances were somewhat uncertain and their first cost was high. Under these conditions the three-voltage-rating was justified inasmuch as it provided a means whereby light

could be readily obtained at minimum cost with different power rates. Now, however, the lamps are low in price and their performance is uniform, hence, it appears, the three-voltage-rating is undesirable.

170. The Life of an Incandescent Lamp (that is, the *useful* life) is always understood to mean the total hours of burning before the candle-power drops to 80 per cent. of the initial, unless the lamp becomes useless because of broken filament, or other cause prior to this. *The total or burnout life* of a lamp is the hours burning before failure of the filament.

171. 220-volt vs. 110-volt Incandescent Lamps.—A number of 220–440-volt 3-wire direct-current systems have been installed with the idea of saving copper over that required for the 110–220-volt volt system. A comparison of lamp ratings shows that the 220-volt lamp—whether carbon, metallized or tungsten—has a much lower efficiency than the 110-volt lamp, costs more, and cannot be secured at all in the smaller sizes. Unless the load is composed so largely of motors that the lamp efficiencies and costs are overbalanced—which is not usually the case in these installations—it will be found that the saving effected by the use of 110-volt lamps will overbalance the saving in copper or the convenience effected by the higher voltage system.

172. Bases for Incandescent Lamps.—Standard nomenclature in this respect has been changed recently. One of the important changes is the substitution of the term "Screw" for "Edison" as applied to bases. The term "Bayonet" base has been adopted in place of the term "Ediswan" base. The classifying adjectives, "Medium" and "Mogul" have been adopted in place of the words "Large" and "Street Series" which were formerly used. Lamp bases may be divided into three general classes, as the base in a general way determines to which of the three styles the lamp belongs. (1) *Medium bases*, generally used with large lamps. (2) *Small bases*, generally used with candelabra and miniature lamps. (3) *Mogul bases*, generally used with street series lamps. Standard lamp bases are illustrated and their dimensions given in the author's AMERICAN ELECTRICIANS' HANDBOOK.

SECTION 5

ARC LAMPS

173. The Principle of the Arc Lamp.—If two pieces of carbon are connected in series in an electric circuit and brought together, current flows through them. Because of the fact that the contact between the two pieces of carbon is poor, due to the nature of the material (carbon), considerable heat is developed at the point of contact. If the two carbons are now slowly separated, the resistance of the contact increases until the heat developed becomes sufficient to vaporize the end of one or of both of the carbons. This vapor constitutes a conducting path for the current after the carbons are separated and the current flows through this vapor, forming an electric "arc."

174. Instability of the Arc.—The electric arc, that is, the stream of vapor between the two carbons or electrodes, offers a certain resistance to the flow of current. It is a curious fact, however, that if by any means (for instance, by raising the voltage slightly) the current should be increased, the resistance of the arc would diminish, thus allowing more current to flow and causing a further decrease in resistance, so that the current would continue to increase. On the other hand, if the current should be decreased, the resistance would increase, causing a still greater decrease of current which would cause a further increase in resistance, until the arc "goes out." In other words, *with constant arc length, the resistance of the arc varies inversely as the current flowing through it.* This feature is of little consequence with series lamps, where the current is maintained constant by the generator or regulator, but with multiple arc lamps a ballast must, as hereinafter described, be provided to correct for it.

175. Steadying Resistance.—To compensate for the instability of the arc, mentioned in the preceding paragraph, resistance of the proper value is inserted in series with it. The effect of this resistance is shown in the graphs* of Fig. 83.

* C. P. Steinmetz, General Lectures on Electrical Engineering.

Curve *I* shows the voltage drop across the arc at various currents. Any increase in current causes a lower voltage drop in the arc so that, on a constant voltage circuit, the current will increase to a short-circuit. Curve *II* shows the voltage drop across the resistance, of 8 ohms in this case. Curve *III* shows the total voltage drop across the arc and resistance. If this arc and its resistor in series were operated at 6.6. amp. it would require 120 volts as shown by curve *III*. If for any reason the current should drop momentarily to, say, 5½ amp., the total voltage required would be 115, but as the line voltage is 120, the current will increase immediately to about 6.6. amp. Should the current tend to rise, the increased voltage required

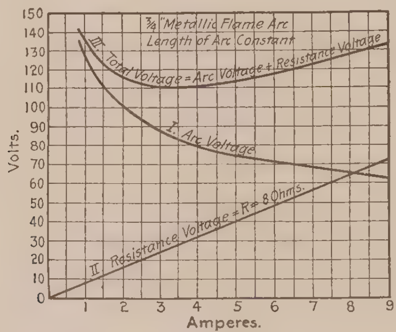


FIG. 83.—Effect of steadying resistance in arc lamp.

to maintain it at the higher value will not be available and the current will again decrease to 6.6 amp. Below a current value of about 3½ amp., however, the arc would still be unstable unless more resistance were inserted. For different resistances and different grades of carbon, different values would result. There is a specific minimum amount of resistance that will maintain an arc stable at a given current. The lower the current, the greater the resistance which will be required.

176. Steadying Reactance.—In alternating-current arc lamps a reactance is used for a "ballast" instead of a resistance. This produces the same effect as the resistance, curve *III*, Fig. 83, but much less energy is lost in a reactance than in an equivalent resistance.

177. Length of Arc.—The proper length for an arc depends largely on the carbons used and on the applied voltage. If the carbons of an arc lamp are brought too close together, the arc *hisses*, radiates relatively little light, and a mushroom-shaped deposit forms on the negative electrode. If the carbons are separated too far the arc will *jump*, that is, will make little jumps out of the crater and tend to run up the side of the positive carbon. If the carbons are still farther separated, the arc will *flame* and become very unsteady. As *hissing*, *jumping* and *flaming* arcs give unsatisfactory illumination, an automatic regulating mechanism is, in commercial arc lamps, provided to keep the arc at its proper length. The essential principles of arc-lamp mechanisms of several types are discussed below.

178. Plain and Cored Carbons.—A cored carbon consists of the same material as solid or plain carbons, but it has a longitudinal hole through its center the entire length of which is filled with a softer carbon. A cored carbon will often steady an arc that tends to flame. Ordinarily, direct-current arc lamps operate satisfactorily with solid carbons. However, if the voltage of the circuit fluctuates very badly, so that the arc tends to jump or go out, a cored carbon will probably insure a steadier arc. It is usual to use one cored carbon with one solid one, as the softer carbon has a shorter life. The cored carbon may be used as either the positive or the negative electrode.

179. Arc-lamp Mechanisms.—Since the carbon electrodes of an arc lamp are consumed as the lamp "burns," it is necessary to provide, in actual arc lamps, a mechanism which will automatically maintain the arc length and the current intensity approximately equal at all times. This is accomplished with suitable arrangements of solenoids and mechanical movements. There are a number of different schemes which have been utilized. The "feeding mechanism" may be actuated by a solenoid in series with the arc (Fig. 84). Or the solenoid may be connected in shunt across the arc (Fig. 85) so that the current which actuates it will be proportional in intensity to the potential difference across the arc. A combination of the series and shunt mechanisms (Fig. 86) is also widely used.

180. A Series-coil Mechanism (Fig. 84) is used in constant-potential lamps, to maintain the current constant. Any momentary increase in current strengthens the magnetic pull of the solenoid on its core and lengthens the arc, thereby in-

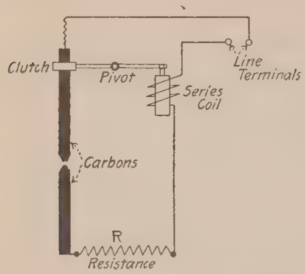


FIG. 84.—Arc lamp mechanism with series regulating coil.

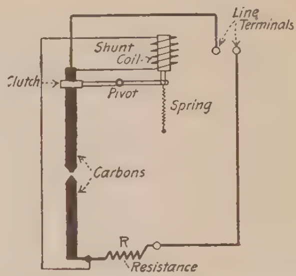


FIG. 85.—Arc lamp mechanism with shunt regulating coil.

creasing the resistance of the arc and reducing the current. Weakening of the current weakens the pull of the coil and allows the carbons to come closer together, thus reducing the arc resistance and permitting the current to increase.

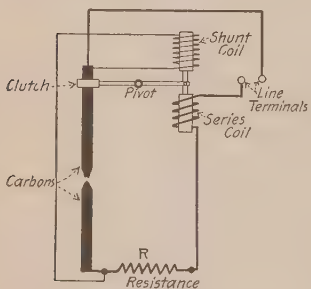


FIG. 86.—Differential arc lamp mechanism.

181. A Shunt-coil Mechanism (Fig. 85) may be used to maintain constant arc length in a lamp operated in a constant-current circuit. If the arc becomes too long, the voltage drop over the arc increases, and the increased pull of the shunt coil decreases the arc length. If the arc becomes too short the pull of the coil is weakened and the spring (or gravity) increases the arc length. This type of mechanism is seldom used, the differential mechanism (Art. 182) giving more satisfactory results and also assisting in the regulation of the circuit.

182. Differential Mechanism.—Practically all lamps which are operated in constant-current circuits, or which are operated in series multiple on constant-potential circuits are provided

with a differential mechanism, in which the pull of a shunt coil is balanced against the pull of a series coil, Fig. 86. Thus if the current increases somewhat the voltage over the arc is increased, and as this same change occurs in all the lamps, the current taken from a constant potential source is reduced, while on a series circuit the lamps assist the regulator in maintaining the current constant. The shunt coils insure that the total voltage over the circuit will be equally divided among all the lamps.

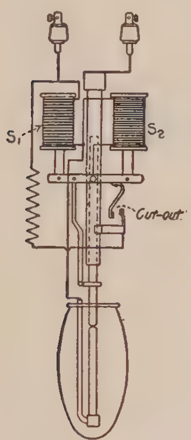


FIG. 87.—Circuits of a series arc lamp.

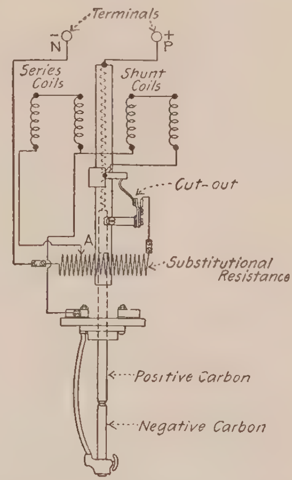


FIG. 88.—Circuits of a multiple-series lamp.

Constant-current lamps are provided with an automatic cutout (Fig. 87), which short-circuits the lamp when the voltage across the shunt coil exceeds a certain value. Series-multiple lamps (Fig. 88), are provided with a "substitutional resistance" which is cut into the circuit as a substitute for the arc when the shunt voltage becomes excessive.

183. The Mechanism of a Series Arc Lamp utilizing the differential-coil principle is diagrammed in Fig. 87. If, for any reason, the voltage drop across the arc becomes excessive, the shunt coil pulls on its plunger, closing the cutout and cutting the lamp out of circuit.

184. Characteristics of Carbon Arcs.—Relatively little of the light flux from a carbon arc is radiated from the "arc stream" itself. The carbons of a direct-current arc burn to the shape

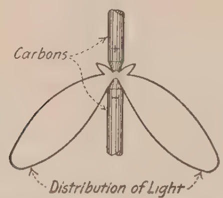


FIG. 89.—Direct-current open carbon arc, showing shape of carbons and natural distribution of light.

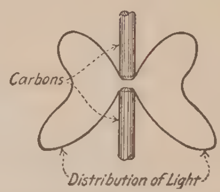


FIG. 90.—Alternating-current open carbon arc, showing shape of carbons and natural distribution of light.

shown in Fig. 89, the positive burning away twice as fast as the negative. Most of the light comes from the "crater" in the positive carbon. This gives a natural light distribution shown

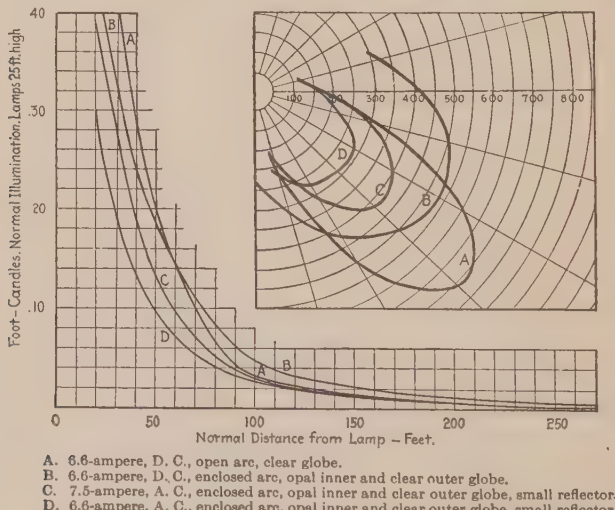
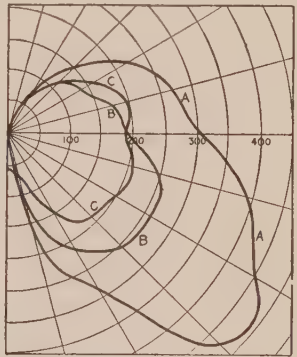


FIG. 91.—Light distribution and illumination curves of typical carbon arc lamps.

by the line in Fig. 89. In an alternating-current arc (Fig. 90), each of the carbons is alternately positive and negative, both carbons have practically the same temperature and are there-

fore equally luminous, and the natural distribution is therefore the same above and below the arc. Care should therefore be taken always to see that a direct-current carbon arc is so connected that the upper carbon is positive if the light is to be thrown downward. By means of reflectors the natural distribution curve can be widely varied. Typical distribution curves of series carbon arc lamps are shown in Fig. 91 and of multiple carbon arc lamps in Fig. 92.



A. 5.5-ampere, D. C., enclosed arc, 110 volts.
B. 3.5-ampere, D. C., enclosed arc, 110 volts.
C. 5.0-ampere, A. C., enclosed arc, 110 volts.

Fig. 92.—Light distribution of typical multiple carbon arc lamps with clear outer and opal inner globes.

185. The Open-flame Carbon Arc is dirty, giving off offensive fumes, and is very costly to maintain on account of the short life of the carbons, which are quite expensive. These defects have been overcome by enclosing the arc in an airtight chamber.

186. Open and Enclosed Arc Lamps (Fig. 93).—When the air can circulate freely about the arc, the carbons are burned

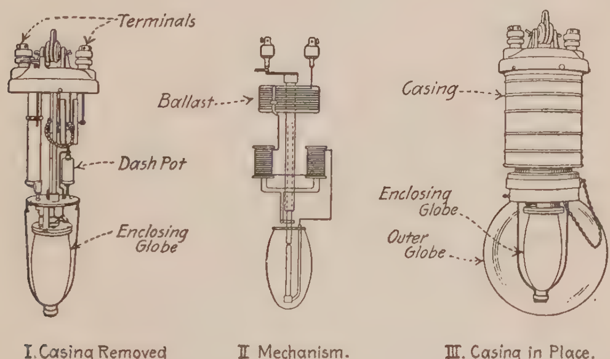


Fig. 93.—Typical enclosed carbon arc lamp. (Multiple type.)

away very rapidly. This is what occurs with "open arcs," which term includes those having a large globe into which air

can enter freely. To prevent the rapid oxidation of the carbons and also to render the arc more steady, an inner globe, almost air-tight, is provided on all modern carbon arc lamps. This globe and the "gas check" or cap are so designed that just enough air is admitted to insure the consumption of the carbon vapor so that it will not deposit on the globe. The increase in life of carbons that results from enclosing the arc is indicated in Table 188. The carbons of an enclosed carbon arc lamp should burn 100 hr. on alternating current and 150 to 180 hr. on direct current if properly operated. Also as the air is excluded the carbons can be burned farther apart, resulting in better light distribution.

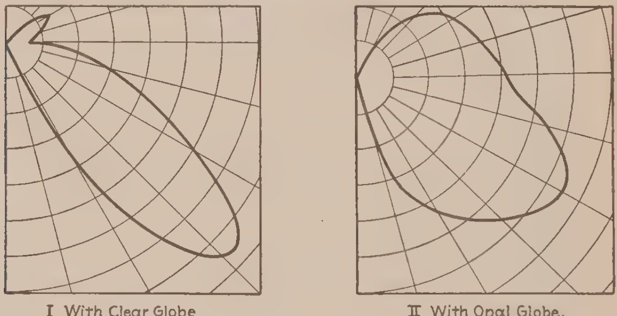


FIG. 94.—Distribution curves of direct-current open arc lamps.

To Secure Satisfactory Operation of an Enclosed Arc care is necessary in the selection of carbons, both as to exact size and quality. Sufficient air must be admitted to unite with the carbon vapor as it is given off or it will deposit on the globe; too much air will greatly decrease the life per trim. If the diameter of the carbons is not correct either too much or too little, air will be admitted through the gas check. If the quality of the carbon is poor, a deposit will form on the inner globe and discolor it.

187. Typical Distribution Graphic of Open-carbon Arc Lamps are shown in Fig. 94. The curves shown are for direct-current lamps and show the form of distribution that may be expected under average conditions.

188. Properties of Carbon Arc Lamps.*

	Kind of lamp	Amp.	Volts, ext.	Volts, arc	Watts	M.s. c.p.	M.h.s. c.p.	Watts: Per m.s.c.p.	Watts: Per m.h.s. c.p.	Hr. life	Carbons, etc.
Open	D.c. series—clear outerglobe	6.6	50	48	380	265	895	1.25	0.82	18	2 prs. ½ in. round.
Open	D.c. series—clear outerglobe	9.6	50	48	480	460	690	1.02	0.71	18	2 prs. 5–8 in. round.
Open	D.c. mul.—2 on 110 v.	9.6	55	48	528	389	...	1.35	....	14	
Open	D.c. mul.—2 on 110	15.0	55	48	530	300	...	1.77	....	13	
	Reflector and d.c. miniature—opal inner, semi-enclosed.	4.1	110	83	451	218	332	2.06	1.36	50	¼ in. carbon.
Enclosed	D.c. multiple—no reflector, opal inner globe	5.0	110	80	550	220	276	2.5	1.98	100	½ × 12 in. carbon.
		6.0	110	80	660	290	365	2.27	1.81	to	
		7.0	110	80	770	358	450	2.15	1.71	150	
		8.0	110	80	880	425	535	2.07	1.64		
Enclosed	D.c. series—reflector, clear globes	6.6	75	73	495	290	479	1.71	1.03	125	½ × 12 in. carbon.
Enclosed	A.c. multiple—no reflector, opal inner globes	4.0	104	72	287	90	105	3.19	2.73	100	½ × 12 in. carbon.
		6.0	104	72	430	167	188	2.57	2.28		
		7.5	104	72	540	225	255	2.4	2.12	to	
		10.0	104	72	720	320	363	2.25	1.98	125	½ × 12 in. carbon.
Enclosed	A.c. series—clear globe	6.6	77	72	425	144	232	2.95	1.83	125	½ × 12 in. carbon.
Enclosed	A.c. series—clear globe	7.5	77	72	480	173	291	2.77	1.65	100	
Enclosed	Intensified—reflector and opal inner globe	5.0	110	80	550	225	414	2.44	1.33	80	2 upper ¼ in., 1 lower 3–8 in.

* SOUTHERN ELECTRICIAN.

189. Magnetite, Luminous, or Metallic-flame Arc Lamps (Fig. 95).—There are several forms of lamps utilizing one electrode of metal. This metal electrode lasts for a long period. For the other electrode a pencil of one of the metallic oxides is used. These lamps combine the principles of the carbon arc and the flame arc (Art. 190) in that both the arc stream and the electrodes are highly luminous. They have the peculiarity that the negative electrode burns away while the positive electrode is consumed very slowly. This limits

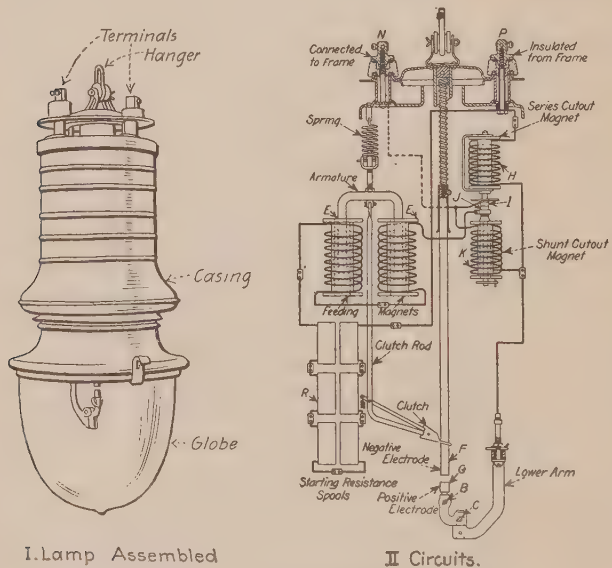


FIG. 95.—Metallic flame arc lamp.

the lamps to operation on direct-current circuits. The negative electrode is a very poor conductor when cold and therefore a conducting wire is usually run through its center to carry current to the arc, the electrode serving principally as a supply of substance to be burned in the arc. In one make of this lamp the negative electrode is placed at the bottom and in another at the top.

The negative electrode (Fig. 96) or cathode has a life of

160 to 200 hr. The arc flame is brightest near the negative electrode and decreases in brilliancy and volume as it nears the positive electrode. Mechanisms (Fig. 95) in these lamps feed the negative electrode intermittently by restriking the arc. When the lamp is connected in the circuit, the feeding magnets are energized, bringing the electrodes together and striking the arc. A shunt magnet connected around the arc acts when the length of the arc has been sufficiently increased. This closes a contact which short-circuits the arc, causing the feeding magnets to strike the arc again with sufficient force to dislodge any drops of slag which may have accumulated.

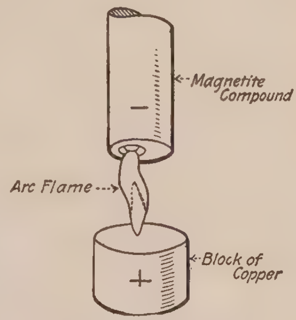


FIG. 96.—Electrodes of metallic flame lamp.

The magnetite arc is well adapted for series operation with

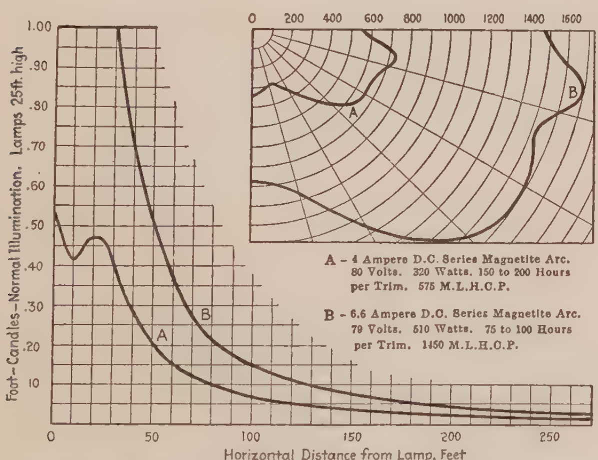


FIG. 97.—Light distribution and electrical performance of typical magnetite arc lamps. (Wickenden.)

low currents.* The 4-amp. lamp designed for series operation at 80 volts per lamp has been widely used for street

* Wickenden.

illumination. The 6.6-amp. lamp has a much higher efficiency and a somewhat shorter life per trim. The light distribution and electrical performance of typical magnetite lamps is indicated in Fig. 97.

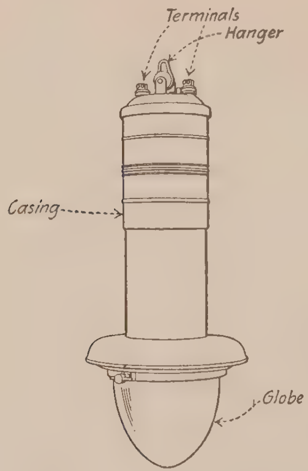


Fig. 98.—Flame arc lamp.

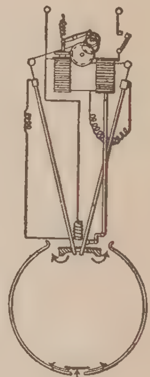


Fig. 99.—Diagram of inclined carbon-flame arc lamp.

190. Flame Arc Lamps (Figs. 98 and 99).—Any carbon arc can be made to flame by increasing the arc length or the current density. However, such a flame gives off little or no light and hence is undesirable. By feeding into the arc

Fig. 100.—Typical construction of flame arc-lamp electrodes.

certain metallic salts the arc flame can be made to produce light—the color varying with the metal used. Calcium—especially calcium fluoride—produces a yellow-colored light of very high efficiency. Strontium salts produce a reddish

color and barium and titanium salts a brilliant white, at a somewhat reduced efficiency. The metallic salts are introduced into the flame by using either carbons cored with a mixture of soft carbon with the desired salt or salts or an electrode which is impregnated throughout with the desired compound. Typical electrode constructions are indicated in Fig. 100. The carbons may be vertical, and co-axial as in the ordinary arc, but in most open-flame lamps they are inclined in a V-shape, as shown in Fig. 99. There is thus no obstruction to the radiation of light below the horizontal. The arc burns

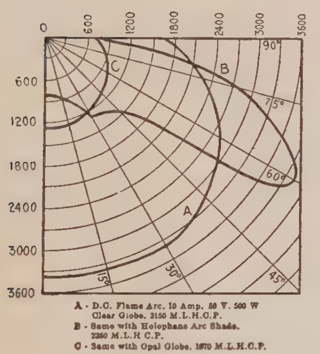


FIG. 101.—Light distribution curves of inclined electrode flame carbon arcs. (Wickenden.)

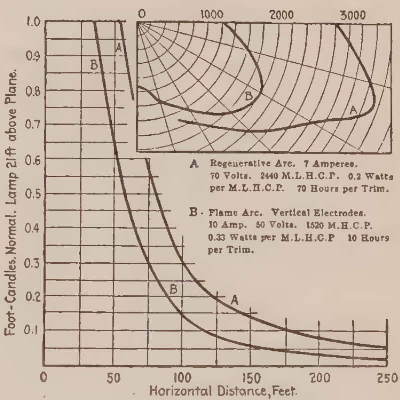


FIG. 102.—Light distribution of flame arc lamps with vertical electrodes. (Wickenden.)

in a cup-shaped economizer of a refractory material (which also serves as a reflector) to shield the arc from air currents, and to prevent it from running up the carbons. A small magnet just above the economizer serves to "blow" the arc downward into a bow shape. Light distribution curves for flame arc lamps are given in Figs. 101 and 102.

191. Long-burning or Enclosed-flame Carbon Arc Lamps.—Several manufacturers have placed on the market flame arc lamps (Fig. 103) constructed on the principle of the enclosed carbon lamp, *i.e.*, having an enclosed arc chamber from which

free access of air is prevented. Some of these lamps have a burning life of as great as 100 hr. per trim. The globe is kept free from the deposit of soot by arranging the air circulation and condensing chambers (Fig. 103) in which the fumes deposit. These lamps preserve the advantage of the flame arc lamp—high light efficiency—and do not have most of its objectionable features.

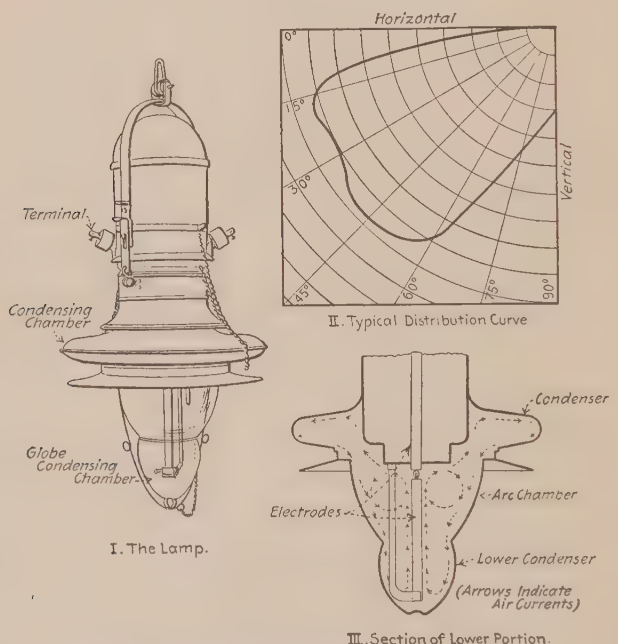


FIG. 103.—Enclosed flaming arc lamp.

192. The Enclosed-flame Arc Lamp, the arc of which is essentially that of the ordinary open-flame arc lamps, has a burning life per trim of about 100 hr. and compares favorably in light output and in efficiency with the short-burning open-flame arc lamp. To secure long burning life of the carbons, the arc is enclosed in a chamber to which the supply of air is limited, as in the case of the standard enclosed arc lamp. In

the flame lamp, however, the efficiency is reduced very little by the enclosure.

Impregnating salts in flame carbons, after being volatilized, pass from the arc and condense as a white powder. Therefore, when the arc is enclosed the use of some scheme is necessary to prevent this powder from condensing on the glassware where it would obstruct the light. A sectional view of the arc (Fig. 103, *III*) and condensing chambers of an enclosed-flame arc lamp shows how the arc is enclosed. The lower part of the lamp shell constitutes a condensing chamber for the lighter fumes from the arc. In operation the lighter fumes rise up into this chamber and deposit on its cooler surfaces. By reason of the large surface and the absorbing material in the condensing chamber, it is not necessary to clean it except at long intervals. This condensing chamber is separated from the mechanism chamber by a casting, and can be readily cleaned out by the trimmer without removing any part but the globe. The lower part of the globe acts as a condensing chamber for the heavier fumes. As the upper portion of the globe is warm, it attracts no deposit and remains clean to the end of the trim.

The dimensions of the upper carbon are as shown in Table 193. The lamps can be arranged to operate on standard commercial circuits of any voltage, direct or alternating current. In multiple alternating-current lamps the current is 10 amp. and the voltage 43. An auto-transformer mounted in the top of the lamp steps down the voltage from 110 to that required by the arc.

The luminous efficiency of the lamp is 0.25 to 0.40 watt per mean lower hemispherical candle-power. The important features of this type of lamp are its high luminous efficiency; the comparatively low maintenance cost; the superior distribution of light for large areas, and the flexibility of design which adapts the lamp for operation on standard voltages of commercial circuits, both alternating and direct current. The lamp is deserving of special consideration in extensions and particularly for street and industrial illumination.

193. Data on Enclosed-flame Arc Lamps.—

Type of lamp	Amp. at terminals	Amp. at arc	Volts at terminals	Electrical eff., per cent.	Power-factor, per cent.	Net wt. with globe, pounds	Overall length, inches	Upper carbon, size in inches	Lower carbon, size in inches
Series a.c.	10.0	10.0	50	94.0	85	49	36.75	0.79 × 10	0.71 × 8.5
Multiple a.c.	6.0	10.0	110	88.0	65	65	38.75	0.79 × 10	0.71 × 8.5
Multiple d.c.	6.6	6.6	110	63.6	....	49	36.75	0.79 × 10	0.63 × 8.0
Series d.c.	10.0	10.0	52	94.0	....	49	36.75	0.79 × 10	0.63 × 8.0
Series-multiple d.c.	10.0	10.0	55	73.0	....	49	36.75	0.79 × 10	0.63 × 8.0

194. Regenerative Arc Lamps.—The so-called "regenerative" arc lamp (Fig. 104) is a flame arc lamp with its air currents so directed that the fumes from the arc are returned to the arc chamber and there used over again and burned up. The arc is semi-enclosed in a glass globe, having two auxiliary glass tubes opening into it both above and below. A circulation of the vapor is effected by the arc, the heated vapor passing around the circulating tubes from top to bottom

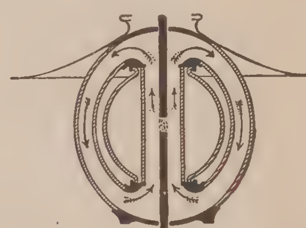


FIG. 104.—Carbon and globe arrangement in the regenerative arc lamp.

and used in the arc many times before condensing. A specific consumption as low as 0.25 watt per mean lower hemispherical candlepower and a life per trim of 70 hr. with the advantage of a wide distribution of light flux is claimed.

195. Light Flux Distribution of Inclined Electrode Flame Arc Lamps.—The light from this type of lamp is given off at its greatest intensity in a direction nearly under the lamp. This is excellent for display lighting but not so satis-

factory for street illumination and for this purpose the light distribution from the lamp is modified with a suitable reflector.

196. Flame Arc Mechanism.—In all lamps with inclined carbons, the two electrode holders are arranged to feed downward at the same rate the + carbon of direct-current lamps being slightly larger to equalize the rate of burning. Standard mechanisms are of three types. In the clock-feed (Fig. 99), the carbons are suspended from a pair of chains wound over a drum, the movement of the drum being regulated through a chain of gears, by a ratchet, controlled by the interaction of the series and shunt coils. When the arc length becomes too great, the pull of the shunt coil exceeds that of the series coil, and the drum is released, allowing the carbons to feed slowly by gravity until the pull of the series coil causes the ratchet to catch and stop the feeding. The arc is struck initially when the current is first turned on, by a third magnet which pulls one of the carbons sideways.

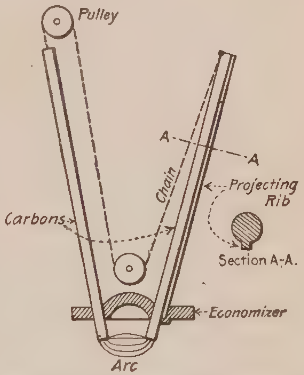


FIG. 105.—Diagram of gravity-feed flame arc lamp.

In the motor-feed lamp (suitable for alternating-current circuits only) the drum on which the chains are wound is coupled or geared to a copper disc which rotates before the shunt and series magnets. The magnets tend to turn this disc in a manner similar to that in which the disc in an induction-type watt-hour meter is rotated, except that the series coil tends to lift the carbons, while the shunt coil tends to lower them. The entire mechanism is thus "floating" in a condition of equilibrium dependent on the relative pulls of the two magnets. The initial arc is struck the same as in the clock-feed lamp.

In the gravity-feed lamps the electrode holders are fastened together with a chain running over idler pulleys in such a manner (see Fig. 105) that both must feed at the same rate. The negative carbon has a projecting rib along its entire length,

which rests on a support at the side of the economizer. As this rib is burned off, both carbons are fed downward. The arc is drawn initially the same as in the other types.

197. Intensified Arc Lamps (Fig. 106).—By using, in these lamps, small-diameter carbons and a high-current density, the temperature of the arc is considerably increased, and the ends of both carbons become incandescent, providing an increased light efficiency with a shorter life. Because of the increased

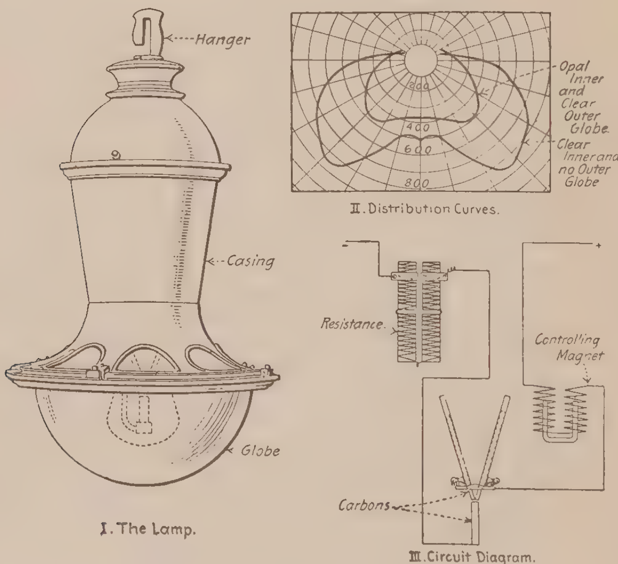


FIG. 106.—Intensified arc lamp.

temperature, the light is nearly white in color, closely approaching daylight in quality. In general, these lamps are quite similar to ordinary enclosed arcs, except in one type, Fig. 106, in which two small upper carbons, arranged in V-shape, are connected in parallel, burning, however, one at a time. When adjusted for 5 amp., and 80 volts at the arc, and equipped with two 12 in. × $\frac{1}{4}$ in. positive and one $3\frac{1}{2}$ in. × $\frac{3}{8}$ in. negative carbon, a life of 75 hr. is secured with an efficiency of about 1 watt per candle with clear globes.

198. Representative Arc-lamp Data.*

Type of lamp	Open or enclosed	Electrodes	Hours per trim	Amperes	Terminal volts	Arc volts	Terminal watts	Arc watts	Terminal power-factor	Watts per m.l.h. c.p.
D.c. series-carbon arc	Open.	+ Upper, solid or cored. − Lower, solid.	9 to 12	9.6	50.0	47	480	450	....	0.60
	Open.	+ Upper, solid or cored. − Lower, solid.	9 to 12	6.6	49.5	47	325	310	....	0.70
	Enclosed.	+ Upper, solid or cored. − Lower, solid.	100 to 150	6.6	72.0	68	475	450	....	0.90
A.c. series-carbon arcs	Enclosed.	One solid. One cored.	70 to 100	7.5	75.0	72	480	450	0.85	1.80
	Enclosed.	One solid. One cored.	70 to 100	6.6	77.0	72	425	400	0.85	2.00
D.c. multiple-carbon arcs	Enclosed.	+ Upper, solid. − Lower, solid.	100 to 150	5.0	110.0	80	550	400	....	2.25
	Enclosed.	+ Upper, solid. − Lower, solid.	100 to 150	3.5	110.0	80	385	280	....	2.35
A.c. multiple-carbon arcs	Enclosed.	One solid. One cored.	70 to 100	6.0	110.0	72	430	375	0.65	2.40
	Enclosed.	One solid. One cored.	70 to 100	4.0	110.0	72	285	250	0.65	2.60
D.c. flame arcs	Open.	Mineralized inclined.	10 to 16	8.0	55.0	45	440	360	....	0.45
	Open.	Mineralized inclined.	10 to 16	10.0	55.0	45	550	450	....	0.40
	Open.	Mineralized vertical.	10 to 16	8.0	55.0	38	440	304	....	0.45
	Open.	Mineralized vertical.	10 to 16	10.0	55.0	38	550	380	....	0.40
Regenerative	Semi-enclosed	− Upper carbon. + Lower carbon, mineralized.	70	5.0	....	70	....	350	....	0.26
A.c. flame arcs	Open.	Mineralized inclined.	10 to 16	8.0	55.0	47	374	338	0.85	0.60
	Open.	Mineralized inclined.	10 to 16	10.0	55.0	47	467	423	0.85	0.55
	Open.	Mineralized vertical.	10 to 16	10.0	55.0	40	467	360	0.85	0.55
Magnetite	Open.	+ Copper. − Metallic oxide.	150 to 180	4.0	80.0	78	320	312	....	0.70
	Open.	+ Copper. − Metallic oxide.	70 to 100	6.6	80.0	78	528	515	....	0.45

NOTE.—Values of watts *per mean lower hemispherical candle-power* are approximate for open carbon arcs and magnetite arcs with clear globes, enclosed carbon arcs with opalescent inner globes and for flame and regenerative arcs with opal globes.

* Wickenden.

199. Color-matching Arc Lamp.—The intensified arc normally gives a light which very closely approaches daylight in color. For exact color matching, however, the light must be slightly modified. A screen of vari-colored glass, if properly selected, will remove the excess red, orange and violet rays found in the normal light from the lamp, and give a color closely approaching that from the north sky. Lamps arranged in this manner are often installed in small enclosed rooms in dry goods stores for color matching.

200. Care of Arc Lamps.—All arc lamps require periodical trimming and cleaning. If once properly adjusted and given sufficient care, they should not require readjustment except at long intervals. The following list of possible troubles and their remedies should assist in adjusting the most common enclosed carbon arc lamps originally and in locating any trouble should it occur. The list is divided into main classes of troubles and these subdivided and classified to render it easy to "run down" a trouble. Owing to the variety in lamp mechanisms adopted by various manufacturers it is impossible to give all the possible remedies for troubles for all lamps.

201. Carbon Arc Lamp Troubles.

ARC TROUBLES.

A. Hissing may be due to
- (1) Line voltage too low. If so readjust the lamp for higher arc voltage (longer arc length).
- (2) Arc length too short because carbon slips in clutch.

B. Jumping.
- (*a*) *When lamp is first started;* may be due to
  - (1) Damp or moist carbons.
  - (2) Oily carbons. This may also cause blackening of the globe.
  - (3) Dashpot plunger too loose (if lamp mechanism has a dashpot).
- (*b*) *Continued jumping;* may be due to
  - (1) Line voltage too high. If so readjust the lamp for lower arc voltage (shorter arc length).
  - (2) Insufficient steadying resistance or part of steadying resistance short-circuited.
  - (3) Excessive variations in line voltage. Adjust the lamp for the average voltage.
  - (4) Carbons not properly aligned.

(5) Poor carbons. If due to this cause jumping in a direct-current lamp may be remedied by using one cored and one solid carbon (see Art. 190).

C. Flaming.

(*a*) *When lamp is first started* but disappearing later; may be due to
(1) Too much air in the inner globe.
(2) Inner globe too large.

(*b*) *Continued flaming,* globe blackening or even melting; may be due to
(1) Line voltage too high. Adjust the lamp for lower arc voltage (shorter arc length).
(2) Imperfect carbons.
(3) Imperfect ventilation due to imperfect fit of the gas check in the inner globe or carbons too thin.

D. Heavy shadows, cast to one side only; due to
(1) Carbons burning on one side more than the other. An inferior grade of carbon or imperfect alignment may cause this.

II. CARBON TROUBLES.

A. Short life of carbons; may be due to
(1) Carbons too small in diameter.
(2) Cracked or broken inner globe, allowing too much air to enter.
(3) Globe and gas cap do not fit together properly, allowing too much air to enter.
(4) Impure or imperfect carbons.
(5) Flaming or jumping. See troubles I, *B* and *C*.

B. Faces burn diagonally; may be due to
(1) Inferior grade of carbons.
(2) Carbons not properly aligned.

III. MECHANISM TROUBLES.

A. Carbons do not separate; may be due to
(1) No power on circuit. In this case there will be no sparking at all between the carbons if they are pushed together.
(2) Carbons sticking because (*a*) they are too large in diameter or (*b*) gas check is not properly made or has warped and binds the carbons.
(3) Dashpot sticking because dirty or oily. Some dashpots have graphite plungers which are self-lubricating, and such should not be oiled.
(4) Levers and other parts of mechanism sticky and in need of cleaning.
(5) Clutch slipping on carbon because (*a*) the carbon is not of proper diameter, or (*b*) the clutch is worn so that it does not take hold.

(6) Resistance or series coil burned out.
(7) Short-circuit in series coil.

B. Arc continually strikes and goes out; may be due to
(1) Insufficient line voltage to maintain the arc.
(2) Shunt coil may be short-circuited or burned out.

C. Carbons do not come together; may be due to
(1) Carbons burned too short or broken.
(2) Carbons sticking (see III, *A*, 2).
(3) Dashpot sticking (see III, *A*, 3).
(4) Levers and other parts sticking.

IV. INNER GLOBE TROUBLES.

A. Inner globe breaks; may be due to
(1) Flaming arc (see I, *C*).
(2) Moisture in carbons. Carbons should be stored in a dry place.
(3) Moisture or rain on globe. Outer globes should be used on all outdoor lamps to prevent this.

B. Inner globe blackens; may be due to
(1) Impure carbons (see also II).
(2) Oily carbons. Carbons should be kept as clean as possible before use.
(3) Improper ventilation in inner globe resulting in improper combustion.
(4) Flaming of arc (see I, *C*, *b*).

SECTION 6

NERNST, MERCURY-VAPOR AND TUBE LAMPS

202. The Cooper-Hewitt Mercury-vapor Lamp (Fig. 107) consists essentially of two separate elements, the tube or light-giving part, and the operating mechanism. The tube (Fig.

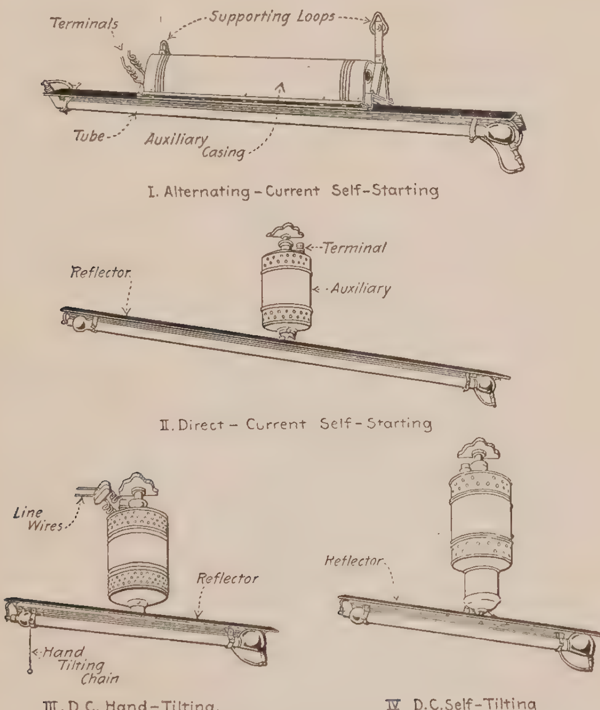


Fig. 107.—Types of Cooper-Hewitt lamps.

108) is of clear glass. The length of the tube used for different services is determined by conditions and may vary from 21 to 55 in. Each tube has an electrode at each end and contains

a small quantity of metallic mercury. The air is exhausted and the tube then sealed. The mercury is held in the large bulb at one end of the tube, and serves as the negative electrode, the tube being always so suspended that this bulb is the lowest part. The positive electrode is a small iron cup at the other end of the tube. The current is conveyed to the electrodes through platinum wires sealed in the glass. The current, flowing from the positive electrode to the negative, vaporizes some of the mercury and causes the vapor to become luminous.

203. The Arc.—It not being feasible to force an alternating current through a mercury arc, the mercury-vapor lamp is, therefore, essentially a direct-current lamp, and gives best results when operating on direct current. However, by providing two anodes, and an auto-transformer, the lamp can be operated on alternating-current circuits by utilizing the prin-

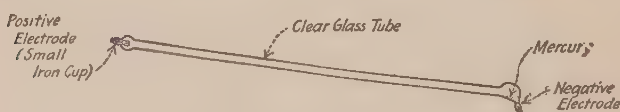


Fig. 108.—Cooper-Hewitt tubes removed from lamp.

ciple of the mercury rectifier. Alternating-current lamps are regularly marketed and are satisfactory in operation.

204. The Quality of Light from a mercury-vapor lamp is peculiar. The light contains no red rays, and has a peculiar bluish-green color, which greatly distorts the color values of objects viewed by it. For applications in which it is not necessary to distinguish color values, two advantages are claimed by its manufacturer for the mercury-vapor lamp: *First*, due to the absence of red rays, it is easy on the eyes, since these rays are the least effective in producing vision, and, owing to their heating power, are irritating and fatiguing to the retina. This may be offset by the preponderance of ultra-violet (Art. 10) rays which are claimed by some to be harmful, although this has not been established experimentally. *Second*, the approximately monochromatic nature of the light promotes acuity of vision, *i.e.*, objects are seen more sharply and details

are more easily discernible than by white light. The lamps are chiefly useful for drafting, photography, and for lighting large manufacturing areas.

205. Ratings of Mercury-vapor Lamps.—Various sizes of lamps are on the market, the ratings given below are typical:

Property	Value
Length of tube overall	55½ in.
Length of tube giving light	50 in.
Diameter of tube	1 in.
Mean spherical candle-power	670 to 850
Watts per mean spherical candle-power	0.52 to 0.51
Power-factor, per cent	about 50
Watts	350 to 430

206. Cooper-Hewitt Lamps Can Be Supplied for All Commercial Voltages for Either Direct or Alternating Current.—The direct-current lamps are designed for circuits of 100 to 124 volts and certain lamps are designed for operation, two in series, on nominal voltages of 220. The alternating-current lamps can be furnished for multiple operation on multiple circuits of nominal voltages of 100, 110, 120, 200, 220 or 240.

207. Efficiency of the Mercury-vapor Lamp.—The Cooper-Hewitt lamp is much more efficient than incandescent lamps of any variety or than the older forms of carbon arcs. It is less efficient than the modern luminous or flaming arcs, the watts per candle being given in the following table.

Type	Length of tube	Average m. h. sp. c.p.	Average watts	Watts per m. h. sp. c.p.
Direct-current	21	300	102	0.64
Direct-current	45	700	385	0.55
Direct-current	50	800	385	0.48
Alternating-current	50	800	400	0.50

208. Cost of Renewal Tubes for Cooper-Hewitt Lamps.—On actual figures taken from 9,947 automatic-tilting direct-

current lamps installed for an average period of 2.87 years each, the cost for renewals was $1.91 per lamp per year. And 2,130 direct-current hand-tilting lamps installed for an average period of 3.59 years each, show a cost of $2.04 per lamp per year.

209. Life of Cooper-Hewitt Lamp Tubes.—An installation of 40 lamps required, during 3.5 years of practically continuous service for twenty-four hours per day, 96 new tubes—an average of 7,944 hours per tube

210. The Automatic Direct-current Starting Mechanism.—Where the lamps are installed high above the floor, or for any other reason are not readily accessible, it is desirable that they be "self-starting." This is effected in one type by providing a small magnet between the lamp mechanism and the tube, which tilts the tube, for lighting, when the voltage is first applied, and is automatically cut out when the lamp starts. In another type, the lamp is not tilted, but the initial high resistance is overcome by applying a high voltage. The high voltage is momentary, at starting only, is confined to the tube and mechanism and is not impressed on the line. It is produced by interrupting the current of an inductance coil in series with the lamp tube, by means of a "shifter," Fig. 109, which consists of a circuit-breaker having a mercury bridge enclosed in an exhausted glass vessel. A metallic coating, called the starting band, is applied on the outside of the negative condensing chamber, at the mercury edge, and is electrically connected to the positive electrode, thereby providing a condenser action. At starting, the circuit is closed through the inductance coil, shifter, starting resistance and series resistance. The inductance coil, on being magnetized, actuates an armature which turns the shifter and breaks the circuit in the mercury bridge.

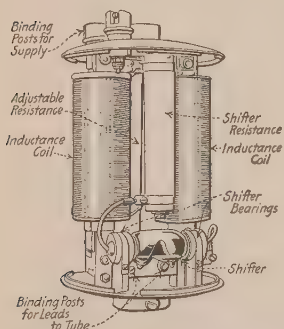


FIG. 109.—Mechanism of automatic starting direct-current Cooper-Hewitt lamp.

The discharge of the inductance produces a high voltage across the terminals and the condensor or permittor formed by the starting band, which breaks down the initial resistance, and starts the arc. The circuit is then maintained by the low-voltage supply current.

211. The Direct-current Operating Mechanism is shown in Fig. 110. It contains two inductance coils, and an adjustable resistance by means of which the current is regulated according to the voltage of the supply. For series lamps, a shunt resistance is cut into the circuit, in case the lamp burns out, by an automatic cutout, which is not provided in the multiple lamps. This type of lamp is started by tipping the bulb, as in the mercury rectifier, usually by pulling a chain or cord.

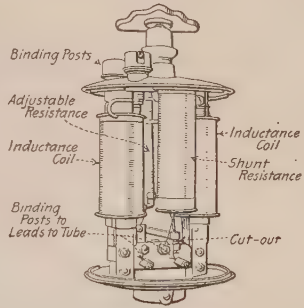


FIG. 110.—Lamp mechanism of non-automatic-starting direct-current mercury-vapor lamp.

212. The Automatic Alternating-current Mechanism, shown in Fig. 111, differs in principle from the direct-current mechanism only in that the inductance is larger, and an auto-transformer is supplied to provide the neutral tap for the rectifying action. The alternating-current lamps are

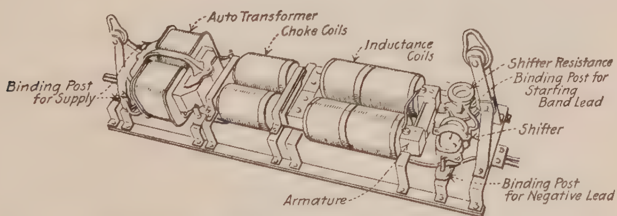


FIG. 111.—Alternating-current automatic-starting mercury-vapor lamp mechanism.

provided with the high-voltage or "shifter" type of automatic starter. They may also be started by tilting the bulb, in which case the automatic features are omitted.

213. Cooper-Hewitt Photographic Skylights (Fig. 112).—On account of their richness in blue, violet and ultra-violet rays, *i.e.*, the so-called actinic rays, and the diffusion caused by the large area of light source, the mercury-vapor lamps are especially adapted for photographic purposes. Skylights are composed of from two to eight tubes, 27 to 52 in. long, mounted side by side, and are used in studios and for moving-picture stages, as well as for printing and enlarging in both photographic and photoengraving establishments.

214. The Mercury-vapor Quartz Lamp.—In common with all other illuminants, the efficiency of the mercury-vapor lamp is increased by increasing its temperature. This may be accomplished, in the case of the mercury-vapor lamp (Fig. 113)

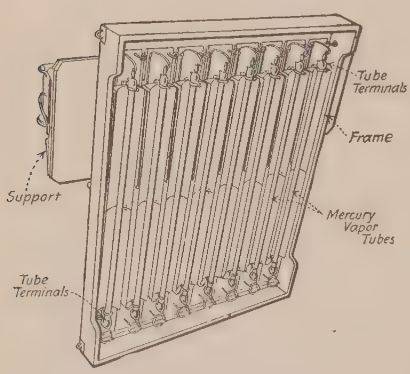


FIG. 112.—The Cooper-Hewitt tube skylight.

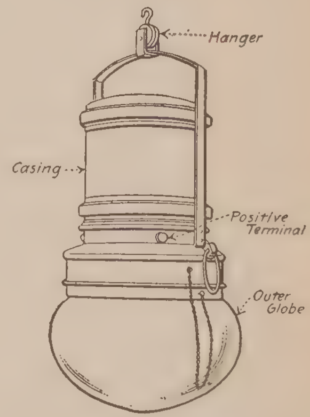


FIG. 113.—Cooper-Hewitt quartz lamp. Type *Z*, 220 volts.

by replacing the long lead glass tube with a shorter one of fused quartz or silica, which is not effected by the much higher temperature. The quality of the light is somewhat similar to that from the glass-tube lamps, but owing to the higher temperature it is whiter, and contains some red and orange rays. The operating characteristics are given in Table 215. The life of the tubes averages about 4,000 hr.

215. Mercury-vapor Quartz Lamp Characteristics.—

Type	Length of tube	Volts	Average watts	Average m.h. sp. c.p.	Watts per m.h. sp. c.p.
Direct-current....	1.25 in.	110	440	1,000	0.440
Direct-current....	4.0 in.	220	770	2,500	0.308

216. The Nernst Lamp.—The light-giving element in the Nernst lamp is a glower composed of metallic oxides which will withstand high temperatures in the open air with very slight deterioration, the average life being about 800 hr. The glower is an insulator when cold, but a fairly good conductor when heated. This requires a heater, which is composed of a metal wire, covered with a refractory protective coating. It is mounted above the glower, its white surface serving also as a reflector, and has an automatic cutout in series which disconnects it from the circuit as soon as current flows in the glower. The glower has a negative temperature coefficient, *i.e.*, its resistance decreases with increase of temperature. So that to limit the current and to obtain stable operation a ballast which has a positive temperature coefficient must be connected in series. This takes the form of a fine iron-wire resistor, which is sealed in a glass tube in a vacuum to prevent oxidation. Both ballast and heater have a comparatively long life.

The lamp operates best on alternating current at 60 cycles. The alternating-current lamp will have a very short life on direct current but a direct-current lamp with special glowers gives very satisfactory life. It is very essential that the direct-current lamp be connected with the right polarity, as otherwise it will burn out in a few hours. The 220-volt lamps are much more satisfactory than are those of the 110-volt type—so much so that small auto-transformer coils are frequently supplied to operate 220-volt lamps from 110-volt circuits. From one to six glowers are operated side by side in a lamp, the efficiency being better with the larger number of glowers, due to the higher operating temperatures. The efficiencies range from 1.2 to 1.5 watts per mean lower hemi-

spherical candle-power. The glowers are made in four sizes, as shown in Table 217. The color of the light is nearly white, and is quite satisfactory for color matching. Nernst lamps are seldom used now, they having been superseded by the more rugged and reliable modern tungsten lamps.

217. Ratings of Nernst Glowers.—

Watts	Candle-power	Watts per candle-power
66	48	1.38
88	64	1.38
110	88	1.25
132	112	1.18

218. The Moore Tube Lamp (see the author's WIRING FOR LIGHT AND POWER for a further description of the construction of and the methods of wiring for Moore tube lamps) consists essentially of a Geisler tube on a large scale. It is composed of a glass tube, 1 to 2 in. in diameter and from a few feet to as high as 250 ft. in length, usually suspended near the ceiling. In operation it can be made to give a soft, and well-diffused light, which is perfectly white, and which, without screening, gives a light suitable for color matching, painting in colors, etc. The lamp operates on alternating current only, at high voltage, the necessary voltage being obtained from the secondary of a small transformer. This transformer is completely enclosed. The ends of the tube are led directly into the transformer case, so that there is no possibility of accidental contact with the high potential conductors. The color of the light can be varied over a wide range by varying the constituents of the gas in the tube. The yellow light is most efficient but is little used. The efficiency with pure white light, which is produced by filling the tube with carbon dioxide, is about 2 watts per candle-power. The principal objection to this lamp is that it is difficult to install and repair, and it requires a rather complicated valve mechanism to maintain the gas in the tube at the correct pressure.

SECTION 7

PRINCIPLES OF ILLUMINATION DESIGN

219. Illumination Design or illumination engineering is an art requiring considerable skill and experience on the part of the designer if every problem which is confronted is to be successfully solved. The methods indicated herein are rather general in application and provide only reasonably accurate estimates unless they are supplemented with such corrections as are dictated by the skill of the experienced designer.

220. General Principles of Illumination.—The general purpose of illumination is to enable things to be easily seen. As

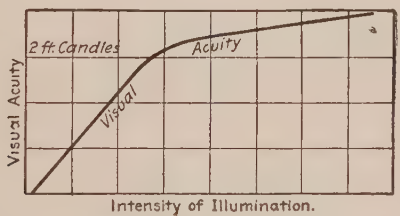


FIG. 114.—Characteristic curve of visual acuity.

things are seen by the light reflected from them into the eye, it is necessary to have the lighting units of such number and intensity and so arranged as to make the things it is desired to see most easily seen. To do this, account must be taken of the effect of illumination on the eye. Before attempting to lay out an illumination scheme one should be familiar with the facts outlined under *Physiological Features of Illumination*, Art. 260.

221. Visual Acuity.—Experiments have shown that if the intensity of illumination is gradually increased the following

facts are noticeable: *First*, that a certain definite intensity of illumination is required before the object can be distinguished. *Second*, that as the intensity of illumination is increased, the *visual acuity* is increased in proportion. That is, the object becomes more easily seen, up to a certain intensity of illumination. *Third*, that beyond a certain value, increasing the intensity of illumination does not result in a proportional increase in visual acuity. This is shown graphically in Fig. 114. It is therefore apparent that more than a certain amount of illumination, depending on conditions and purpose, is wasteful, in that it does not render things any more readily seen.

222. Glare.*—The effectiveness of illumination is depressed to a marked degree by certain disturbing influences which have been grouped under the term "glare." Glare may be, approximately, defined as *the relative overbrightness of part of the field of view.* TRANSIENT GLARE, caused by the slowly changing adaptation of the eye when emerging from a dim region into a brilliantly lighted one, causes only temporary discomfort. PERSISTENT GLARE, in addition to the depression of visual functions, may be highly injurious. No complete quantitative analysis of glare has yet been made. The following qualitative relations have been well established:

(*a*) GLARE EFFECT, OR REDUCTION OF VISUAL EFFECTIVENESS, INCREASES AS THE GLARING SOURCE APPROACHES THE EYE. Glare increases as the ratio of the distance of the glaring source to that of the visualized object from the eye diminishes. The distance at which a light source ceases to be glaring depends on its intensity, brilliancy and position in the field of view.

(*b*) GLARE INCREASES WITH THE QUANTITY OF LIGHT RECEIVED FROM THE SOURCE.

(*c*) GLARE INCREASES WITH THE BRILLIANCY OF THE GLARING SOURCE AND WITH ITS DEGREE OF CONTRAST TO OBJECTS VISUALIZED.—An automobile headlight is exceedingly glaring at night, but not glaring by day. Any light source giving an *afterimage* is excessive in brilliancy. Glare due to this cause is accentuated by the reflex tendency of the eye to wander from the object of vision and fix on the brilliant source, causing a fatigue of attention.

(*d*) GLARE INCREASES AS THE RETINAL IMAGE OF THE GLARING SOURCE APPROACHES THE CENTER OF THE FIELD OF VIEW.—Depression of

* W. E. Wickenden in AMERICAN HANDBOOK FOR ELECTRICAL ENGINEERS, page 1785.

vision from side light is due in part to contrast and in part to the dilution of the central image by light scattered in the eye. Glare due to bright walls and backgrounds is largely of the latter class. The glare from bright sources situated at an angle from the line of vision exceeding 26 deg., is generally negligible.

223. The Chief Practical Causes of Glare* are due to: (1) directly visible light sources of high power and brilliancy; (2) scattered light from side sources and backgrounds; (3) direct reflection of bright images by glazed surfaces in the immediate field of view.

224. Prevention of Glare Should be Sought† by: (*a*) the proper location and shading of light source; (*b*) creating suitable contrasts between the field and its surroundings; and (*c*) avoiding the use of glazed surfaces, especially highly sized paper and similar things.

225. Glare and Its Effect on the Functions of the Eye may be explained thus:* Glare results wherever, during any infinitestimal or greater period of time, an amount of light continues to fall upon the actively visualizing portion of the retina of the eye sufficient in quantity to induce therein chemical changes more rapidly than the regenerative functions of the eye can compensate for them. Thus, when an eye—which has for some time been exposed to conditions of darkness with the resultant expansion of the pupil—is suddenly exposed to light even of low-intensity, glare results. An excessive amount of light then impinges on the retina, through the expanded pupil, and its regenerative functions cannot keep pace with the chemical changes induced. Upon further exposure the pupil contracts rapidly; the regenerative functions regain their normal control, and the glare effect ceases. If now, however, the eye be exposed to a light of still greater and of such intensity that the very limited range of pupillary contraction is unable to compensate for it or if an even moderately bright light source is introduced near the center of the field of vision glare is again experienced. This glare effect, after a brief period, attains a state of equilibrium, characterized by a definite decrease in

* W. E. Wickenden in AMERICAN HANDBOOK FOR ELECTRICAL ENGINEERS, page 1785.
† W. E. Wickenden in AMERICAN HANDBOOK FOR ELECTRICAL ENGINEERS.

efficiency of vision. This lowering in efficiency of vision thereafter increases in magnitude rather slowly. We may, therefore, for convenience designate a glare condition as:

(*a*) TRANSIENT, *when it results from the inability of the pupil to adjust itself instantly to a changed condition of light intensity.*

(*b*) PERSISTENT, *when it results from a light intensity exceeding that for which the contraction of the pupil can compensate* —or when it results from a light source near the center of the field of vision.

226. The Presence of Strong Shadow Contrasts Tends to Produce Transient Glare.*—The evil effect of the shadow contrast lies in the demand it introduces for instantaneous changes of considerable magnitude in the diameter of the pupil of the eye, when the eye is directed from the shaded to the unshaded area, or *vice versa.*

227. Economical Intensities.—The intensities of illumination tabulated in 228 are recommended for the various services indicated. Only a few typical values are given in this table. A much more complete table covering many classes of service is given in the author's AMERICAN ELECTRICIANS' HANDBOOK. These intensities enable objects to be seen with all the clearness generally necessary in the places mentioned. Thus, in draughting rooms greater intensity is required than in swimming-pool buildings, because more detail must be brought out. On billboards greater intensity is required than in a library reading room, to enable the signs to be read at a great distance.

228. Economical Densities of Illumination in Foot-candles.†—Refer to the author's AMERICAN ELECTRICIANS' HANDBOOK for a considerably more comprehensive table of economical intensities.

* Sweet in JOURNAL FRANKLIN INSTITUTE, May, 1910, Vol. 169, page 359.

† National Electric Lamp Association.

Application	Foot-candles	Application	Foot-candles
Auditorium	2.0	Machine shop—	
Billboard	8.0	Rough work	2.0
Church	2.0	Average work	4.0
Draughting room	8.0	Fine work	6.0
Engraving	10.0		
		Office (no local lights)	4.0
Factory—			
General illumination only, where additional special illumination of each machine or bench is provided	1.5	Residence—	
		Porch	0.2
		Sitting room	1.5
		Dining room	1.5
		Kitchen	2.0
Local bench illumination	4.0	Hall	0.5
Complete (no local) illumination	4.0	Bed room	1.5
		Bath room	2.0
		Cellar	0.6
Garage	2.0		
		Show window[1]—	
Hotels—		Light goods	7.0
Corridor	0.6	Medium goods	15.0
Bed room	1.5	Dark goods	20.0
Lobby, Dining room	2.0		
Writing room	2.0	Sign	8.0

[1] Depends largely on character of street and other features of location.

229. Economical Densities for Store Illumination.—

Application	Foot-candles	Application	Foot-candles
Butcher	3.5	Furniture	4.5
Clothing	5.0	Grocery	3.0
Drug	4.0	Hardware	4.5
Dry goods	4.0	Millinery	4.0
Florist	3.0	Notions	3.0

230. Lighting Sources Available (Figs. 115 and 116).—The circuit available for serving the lighting units sometimes determines what type of lamp must be used. The following table indicates the types of lamps that can be used on the circuits of the various kinds.

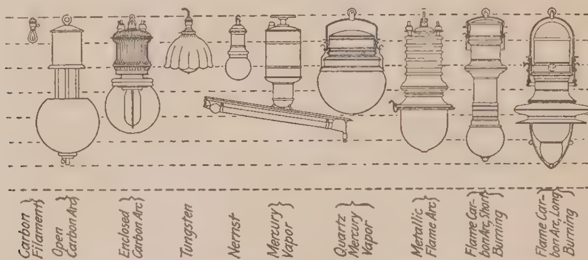


FIG. 115.—Chart showing relative average overall dimensions of various lamps. (Clewell.)

231. Location of the Lighting Units.—No general rule can be given for location of the lighting units for general illumination. It is usually desirable to so distribute the units that uniform

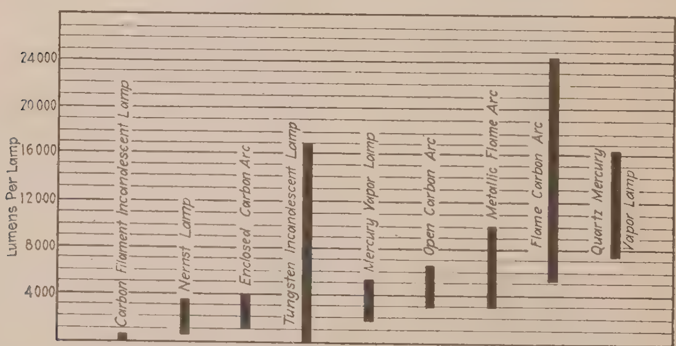


FIG. 116.—Chart showing lumens available from one unit with various lamps. (Adapted from Clewell.)

illumination (Art. 105) will result. Where the number and location of lighting outlets is not determined by architectural considerations, or by the arrangement of the furniture and fixtures, it is desirable to arrange the lighting outlets in the form

230. (*Continued*) **Lighting Sources Available.**

	Carbon or metallized filament incandescent	Tantalum incandescent	Tungsten filament, incandescent	Enclosed carbon arc	Flame carbon arc	Metallic flame arc	Nernst	Cooper-Hewitt
Direct current—								
Series	Yes	Yes	Yes	Yes	Yes	Yes	No	No
110-volts multiple	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
220-volts multiple[1]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
550-volts multiple[1]	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Alternating current—								
Series	Yes	No	Yes	Yes	Yes	No	No	No
110-volts 25-cycle multiple	Yes	No	Yes	[2]	[2]	No	Yes	No
220-volts 25-cycle multiple	Yes	No	Yes	[2]	[2]	No	Yes	No
110-volts 60-cycle multiple	Yes	No	Yes	Yes	Yes	No	Yes	Yes
220-volts 60-cycle multiple	Yes	No	Yes	Yes	Yes	No	Yes	Yes
440-volts 60-cycle multiple[1]	Yes	No	Yes	Yes	Yes	No	No	Yes

[1] Lamps in multiple or in multiple series. [2] Possible but not very satisfactory.

of squares or rectangles. It is important that the units be placed at the centers of the squares and *not at the corners.* Fig. 117 shows this method of locating outlets which is undesirable because it tends to provide a very low intensity of illumination near the walls, as compared with that at the center of the room. Fig. 118 shows the correct way of locating outlets in the centers of the squares. In certain cases, notably in office lighting, it may be desirable, in order to minimize shadows, to place the outer rows of outlets somewhat nearer the side walls of the room than would be the case if symmetrically arranged as shown in the diagram.

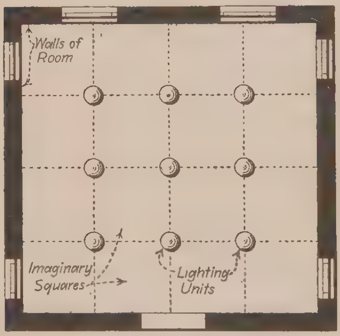


FIG. 117.—Incorrect arrangement of lighting units.

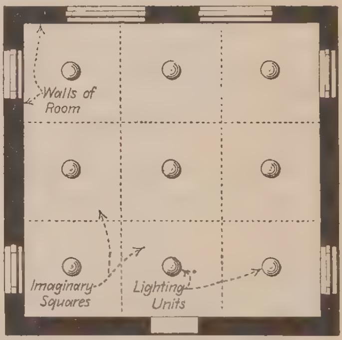


FIG. 118.—Correct arrangement of lighting units.

231a. For a Given Ceiling Height, the Smaller the Squares, the Less Intense Will Be Any Shadows Produced.—The higher the ceiling, the larger the squares can be. As a general rule the side of each square should about equal the height of the ceiling. For offices that have no desk lighting the squares should be smaller, say three-fourths the height of the ceiling, to reduce shadows; for stores the squares can be a little larger. If the room is divided by partitions, each enclosure should be treated as a separate room.

231b. Where the Ceiling Is Divided into Panels or Broken up by Girders, the size and location of these often determine the spacing of the lighting units. In such cases it is advisable to space the units symmetrically as dictated by the locations of

the decorations and girders and then to select lamp sizes and reflectors adaptable to such spacing.

232. Desirable Sizes of Squares.—In lighting large offices, where individual desk lights are not employed, the squares should be comparatively small to insure that the flux illuminating on any one desk will eminate from many units, thus merging the shadows and decreasing the glare due to regular reflection (Art. 120) from the desk. In stores, the squares need not be so small. The size of the squares bears no relation to the intensity of illumination, but only to the evenness of illumination and to the depth of the shadows. The following table indicates the sizes of squares desirable for various spaces for direct lighting. The table cannot be strictly followed in all cases. It is better not to use with the smallest ceiling height in each line the largest size square available for that height. In office lighting with no desk lights, the squares should never be made so large that extensive reflectors (Art. 146) are necessary to obtain uniform illumination.*

Kind of room	Ceiling height	Desirable length of side of square
Armories	12 to 16 ft.	12 to 16 ft.
Auditoriums	12 to 16 ft.	12 to 16 ft.
Public halls	over 16 ft.	15 to 26 ft.
Rinks	over 16 ft.	15 to 26 ft.
Stores	8 to 11 ft.	8 to 11 ft.
Stores	11 to 15 ft.	10 to 16 ft.
Stores	over 15 ft.	14 to 22 ft.
Offices with individual desk lights	10 to 20 ft.	12 to 18 ft.
Offices without individual desk light	9 to 12 ft.	7 to 11 ft.
Offices without individual desk light	12 to 16 ft.	9 to 14 ft.
Offices without individual desk light	over 16 ft.	11 to 18 ft.

233. A Spacing Chart for Prismatic Reflectors† is shown in Fig. 119. Knowing either the spacing or mounting height, the correct reflector and its proper mounting height or spacing can be determined at a glance, or *vice versa*.

* Holophane Company.
† General Electric Company.

EXAMPLE.—Consider an installation for which a spacing distance of 14 ft. has been selected. With this spacing distance, extensive type reflectors call for a mounting height of about 9½ ft. above the floor. This is obviously too low to secure the best diffusion and minimum shadows, so reference is made to the graph in Fig. 119 for the intensive type, and a mounting height of 13½ ft. is found. This gives a distance from ceiling to socket of about 1 ft. with a 15-ft. ceiling.

234. Spacing for Indirect and Semi-indirect Lighting is determined largely by the ceiling height. The distance between units should not, in general, exceed one and two-thirds times the height of the ceiling above the plane to be lighted, draughting rooms and offices where close work is performed should have closer spacings.

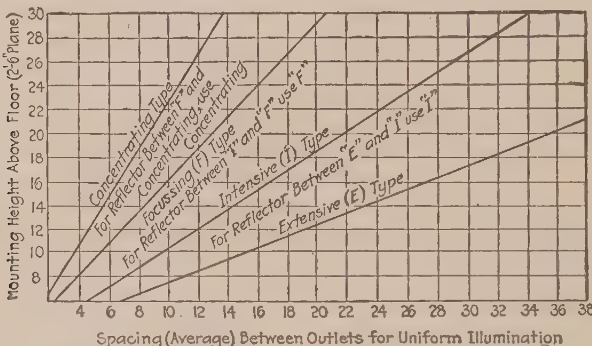


FIG. 119.—Spacing chart for reflectors. (Holophane Company.)

235. Mounting Height means, unless otherwise specified, the distance from the center of the lamp to the plane of illumination (Art. 101), but it may mean the mounting height above the floor, that is, the height from the floor to the lamp.

236. Considerations Relating to the Height and Type of Ceiling or Roof of the Area Illuminated.*—In a manufacturing area, the direct system is almost invariably employed and the lamps are mounted within a foot or two of the ceiling or on stringer boards which span the space between the lowest members of roof trusses at intervals where rows of lamps are deemed necessary. High mounting is desirable because then the lamps are then out of the way of cranes, are less liable to be broken,

* C. E. Clewell in ELECTRIC JOURNAL.

the glare is reduced to a minimum and in the case of a light ceiling there is more reflection and better diffusion of light. The lamp should be lowered in locations where there is horizontal overhead belting, to the level of the bottom of the belting, otherwise a portion of the light is ineffective. Occasionally it may be necessary, for the same reason, to install two or three 100-watt units in a given area where the conditions would otherwise warrant a single 250-watt unit.

In office lighting the direct, indirect, or semi-indirect system may be used. The lower intensity lamps, such as the 60-watt unit, give more satisfactory results than those of higher candle-power. This is due to the fact that with them the glare and inconvenience from shadows is reduced to a minimum. Ordinarily the lamps should be mounted near the ceiling; however, whatever the height of the ceiling, the mounting heights should be approximately the same for any one size of lamp, since it is advisable to standardize as far as practicable the sizes of lamps and reflectors, thus securing from one size the same foot-candle intensity per lamp on the working plane.

In the case of drafting rooms a semi-indirect system with reflection from light ceiling and walls, or diffusers, is effective, the lamps being mounted within a foot or so of the ceiling up to 16 ft. ceiling height. Clusters of four 60-watt lamps (see Fig. 58) on a fixture with opal glass reflectors throwing the light upward, the clusters placed 8 ft. apart from center to center have been found to give excellent results at a mounting height of 14 ft. with a ceiling 16 ft. high.

237. Illumination of Vertical Surfaces.*—An important feature in industrial-plant illumination related to the matter of mounting height, is the furnishing of light at an angle (Fig. 120) so as to illuminate the side of the tool or piece of work. The point at which the tool is making a cut may require light from an angle rather than from a point directly overhead. For a given spacing of lamps, the higher they are mounted the more concentrating must be the reflector to produce the highest efficiency of horizontal illumination on the working surface. This illumination on the horizontal surface may not,

* C. E. Clewell in ELECTRIC JOURNAL.

however, be the most important feature. One way to secure more illumination on the side of machines is to lower the lamps and use more broadly distributing reflectors, so that the light is directed sidewise as well as downward. On the other hand, if the lamps are mounted too low they become objectionable by being in the line of vision (Art. 100) when a man looks up from his work. Thus, in one instance, where the maximum possible mounting height was 13 ft. 6 in. (it was found desirable to place the lamps at this height to avoid glare) the side lighting was secured by using broader distributing reflectors and somewhat larger lamps than ordinarily would have been

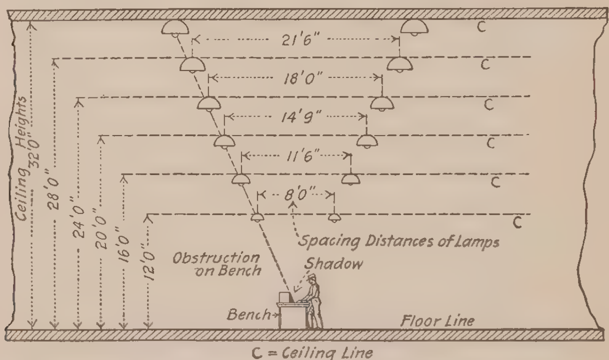


FIG. 120.—Showing relation of shadows to mounting height and spacing.

necessary, thus increasing the horizontal intensity to the same value as with the more concentrating reflectors and smaller lamps, and at the same time providing the necessary side light for the vertical surfaces.

238. The Effect of Mounting Height and Spacing Distance on Shadows is shown in Fig. 120.* For a low ceiling, the lamps must be fairly close together to avoid unsatisfactory shadow effects, and therefore, the size of lamp should be small. For higher ceilings, the spacing distance may be greater for the given shadow effect and the size of lamp correspondingly large.

* C. E. Clewell in ELECTRIC JOURNAL.

239. Approximate Desirable Mounting Heights for Tungsten Lamps.*—

Mounting height, ft.	Size of lamp, watts	Mounting height, ft.	Size of lamp, watts
7 to 10	40		
8 to 12	60	7 to 12	60
10 to 14	80		
12 to 16	100	11 to 16	100
14 to 20	150		
17 to 27	250	16 to 28	250
25 to 35	400		
30 to 40	500	28 to 40	500

240. Desirable Ratios of Mounting Height to Spacing for Reflectors.—

Type of reflector	Ratio: $\frac{\text{spacing}}{\text{height}}$ (Multiply mounting height by following to obtain desirable spacing of lamps)	Ratio: $\frac{\text{height}}{\text{spacing}}$ (Multiply spacing by following to obtain desirable mounting height)
Extensive.............	2.00	0.50
Intensive..............	1.25	0.80
Focussing.............	0.75	1.30
Concentrating.........	0.50	2.00

DISTRIBUTING REFLECTORS are not designed for any particular spacing. Use them for spacings wider than *extensive* where uniform or even illumination is not necessary, as in stockrooms, warehouses and the like.

NOTE.—Where conditions call for reflectors between any two of the above types, use the more concentrating of the two. For example: If a reflector midway between an *intensive* and a *focussing* is indicated by the computations, use the *focussing* type.

241. The Three Methods of Calculating Illumination in General Use Are: (1) the Flux of Light Method, (2) the Watts

* National Lamp Works of the General Electric Co.

per Square Foot Method, (3) the Point-by-point Method which is really a modification of the flux of light method. Each is described in following Arts. Each has its applications and none is suitable for all cases.

242. All of the Methods of Calculating Illumination Given Approximate Data.—They really provide nothing more than reasonably accurate estimates which must be supplemented by the judgment of an experienced designer to afford dependable results. In laying out an illumination installation it is always a good plan to initially install in each outlet a lighting unit of a wattage somewhat larger than that that the estimates indicate necessary. In case there is too much light, a lamp of smaller wattage can be used in each outlet: A tungsten lamp general illumination system is usually very flexible in this respect as units of greater or less wattage can be used in the outlets as conditions demand, increasing or decreasing accordingly the illumination on the working plane.

243. Calculation by the Flux of Light Method.—The simplest method of designing a general illumination installation is by this method which is based on the principle outlined in Art. 76. Knowing the intensity desired (Art. 228) on the surface to be illuminated and its area, the total flux or lumens required to produce that average illumination may be readily computed thus:

$$(36)\quad Lumens = \frac{area\ (square\ feet) \times intensity\ (foot\text{-}candles)}{constant}$$

or expressing the same thing in letters

$$(37)\qquad F = \frac{S \times E_a}{C} \qquad \text{(lumens)}$$

and

$$(38)\qquad S = \frac{F \times C}{E_a} \qquad \text{(square feet)}$$

and

$$(39)\qquad E_a = \frac{F \times C}{S} \qquad \text{(foot-candles)}$$

Wherein. F = the total flux, in lumens, generated by all of the light sources that illuminate the area. S = the area illuminated, in square feet. E_a = the average intensity, in foot-candles, over the entire area of the working plane. C = constant from Art. 245.

Knowing the total lumens required, it is then possible to determine how many lighting units of a certain size—or what size of lamps of a given number—are required to provide the required flux (lumens). The lumens generated in a given lamp can be taken from the table in Art. 247 or from a similar table published by some lamp manufacturer.

244. Illumination Constants.—The flux of light method (Art. 243 above) of calculation is based on the assumption that only a certain proportion of the light flux generated by all of the luminous sources in a room reaches the surfaces to be illuminated. Some of it is thrown on the walls and ceiling, and of this only a part is reflected to the illuminated plane. The following table indicates, approximately, the percentage of the light generated that reaches the illuminated plane under different conditions. The values shown in this table (Art. 245 following) were determined by experiment for the different conditions noted.

The values really represent the per cent. of the total light flux, in lumens, which is generated that is effective in illuminating the working plane. The working plane is taken as being a horizontal plane 30 in. from the floor. The elementary discussion of Art. 76 on which the flux-of-light method is based, and the numerical examples there given, should be reviewed to obtain an understanding of the principles involved.

245. Average Illumination Constants, Per Cent. Lumens Effective, or Efficiency of Utilization.—If the number of total lumens produced by a light source be multiplied by the value (expressed as a decimal) for the conditions applying given below, the number of lumens effective in lighting the area will be the result. See the note in fine print, which follows the table, for further information relative to the situation.

Ceiling	Light	Light	Medium	Light	Medium	Medium	Dark
Walls	Light	Medium	Light	Dark	Medium	Dark	Dark
[1] Prismatic, clear	60	53	..	48	48	45	40
[1] Prismatic, V.F.	53	50	..	45	45	42	38
[1] Holophane-realite	51	47	..	44	45	38	35
[1] Steel, porcelain, aluminum	48	46	..	44	45	44	44
[1] Sudan	50	45	..	42	42	40	37
[1] Druid	48	43	..	39	38	34	31
[1] Druid, semi-indirect	40	37	..	33	25	20	
[1] Sudan, semi-indirect	35	33	..	30	20	17	
[1] Ivanhoe, indirect	31	28	..	25	18	15	
Opal	50	45	44	42	42	40	37
White glass, light density	48	44	43	40	40	36	33
Indirect and semi-indirect	31	28	21	25	19	17	10
Bare lamps	41	35	34	30	30	25	21

NOTE that the above are average, and ordinarily safe, working constants. The actual constant to use in any case will be determined to some extent by the size of the room to be illuminated. For rooms of floor areas of less than 200 sq. ft., the constants used may be smaller than those above given by from 10 to 40 per cent. For rooms of areas larger than 1,000 sq. ft., constants greater than the above—by not more than 15 per cent.—may be used, particularly where the walls are of medium or dark colors.

246. Efficiencies of Utilization for Indirect Lighting.* —

Minimum dimension of room divided by ceiling height	Efficiency of utilization	
	Dark walls	Light walls
1.0	0.20	0.24
1.5	0.22	0.26
2.0	0.24	0.28
2.5	0.28	0.30
3.0	0.30	0.32
3.5	0.32	0.34

NOTE.—The above values are 20 per cent. low, to provide for depreciation due to dust and aging of lamps. With lamps new and reflectors clean, the efficiencies of utilization will be correspondingly higher than given in the table.

[1] Holophane Works data.

* National X-Ray Reflector Company.

247. Approximate Total Lumens Given by Clear, Regular Bulb Multiple Lamps.—The amount of light flux radiated by any electric lamp is a perfectly definite and measurable quantity, the value of which depends upon the wattage of the lamp and the efficiency at which the lamp is burned. In the following table are given a few values of the total lumens radiated by incandescent lamps. Because of the reason that the incandescent-lamp manufacturers are continually revising their data sheets—improving their efficiencies—it is impracticable to maintain a complete and up-to-date table of *lumens generated*, by the various sizes and types of incandescent lamps, in any book which is not revised very frequently. Hence the table given below is abridged and the values quoted in it may be approximate. For a more complete and a frequently revised table of these values see the author's AMERICAN ELECTRICIANS' HANDBOOK. Use of table is explained in Art. 248.

Rated watts	Mazda B or tungsten (vacuum)		Mazda C or tungsten (gas-filled)	
	105–125 volts	220–250 volts	105–125 volts	220–250 volts
10	75			
15	128			
20	178			
25	234	207		
40	381	354		
60	588	541		
100	1,032	937	1,257	
150	1,634	1,490		
200	.....	.....	2,680	2,388
250	2,723			
300	.....	.....	4,310	3,770
400	.....	2,613	5,745	5,282
500	.....	.....	7,180	6,970

248. Example, Flux of Light Method of Calculating Illumination.—Assume we have a notions store to light, the dimensions of which are (Fig. 121): length, 80 ft.; width, 25 ft.; height, 12 ft. 6 in. The ceiling and walls are light. Tungsten lamps with prismatic velvet-finish reflectors are to be used.

Referring to the table in Art. 229 we find that stores of this character should have an illumination of 3.0 ft.-c. The area of the store is 80 $\times$ 25 or 2,000 sq. ft. The illumination constant for prismatic velvet-finish reflectors with tungsten lamps in rooms with light ceilings and light walls is 0.53 (Art. 245). Substitute in the formula (37) thus:

$$F = (S \times E_a) \div C = (2{,}000 \times 3.0) \div 0.53 = 11{,}300 \textit{ lumens.}$$

Now determine the number and size of lamps necessary to supply this quantity of light. In Art. 247 we find that a 25-watt tungsten lamp gives 234 lumens; a 60-watt lamp, 588 lumens; a 100-watt lamp, 1,032 lumens;

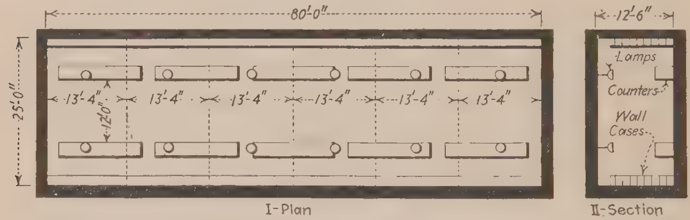


FIG. 121.—Illustrating the flux-of-light method of calculating illumination.

and a 150-watt lamp, 1,634 lumens. (All of the data just given apply to vacuum lamps.)

The number of 25-watt lamps required would be, therefore, 11,300 $\div$ 234 = 48; the number of 60-watt lamps, 11,300 $\div$ 588 = 19; the number of 100-watt lamps, 11,300 $\div$ 1,032 = 11; and the number of 150-watt lamps, 11,300 $\div$ 1,634 = 7.

The lighting should be laid out in squares (see Art. 231). The room would then be 2 squares wide and 6 or 7 squares long, thus requiring 12 or 14 units. Twelve 100-watt lamps would therefore about satisfy the requirements, spaced as shown in Fig. 121. It will be even better to put the lights a little nearer the center of the room than the walls, because of the shelving along the walls. This has been done in Fig. 121.

The reflectors should be selected as indicated in Art. 240. The lamps are spaced 12 ft. to 13 ft. 4 in. apart. The ceiling height is 12½ ft., making the lamps about 10 ft. above the tops of tables and counters. The ratio of lamp spacing to height of lamps is $^{13}/_{10}$ = 1.3. By suspending the lamps at the ceiling the ratio would be $^{13}/_{10}$ = 1.25 (approx.), the correct ratio for average intensive reflectors.

249. Watts per Square Foot Method of Designing Illumination Installations.—Where only one type of lighting unit, the tungsten lamp, for instance, is used and the mounting height of the units falls within the limits specified in 239, this method can

be used. However, the *Flux of Light* is now usually considered the preferable method. The *Watts per Square Foot*, of Table 250, is based on the fact that with a given type of lamp and given conditions, 1 ft.-c. intensity will be produced on the working plane by a certain expenditure (in watts per square foot) of energy. Similar tables can be compiled for illuminants other than tungsten lamps.

In using the method, determine the size of lamp required from Table 239 and the watts per square foot necessary to produce the desired intensity from Table 250. Then:

$$(40)\quad \frac{\textit{Wattage of lamp}}{\textit{Watts per square foot}} = \textit{area of square of which lamp is the center.}$$

Taking the square root of the value representing the area of this square, the length of the side of the square, or the "ideal spacing distance" between lamps is obtained. It follows that

$$(41)\qquad d = \sqrt{A} = \sqrt{\frac{W}{w}} \qquad \text{(feet)}$$

Wherein.—d = ideal spacing distance in feet. A = the area of the ideal square in square feet. W = wattage of each lamp, w = watts per square foot.

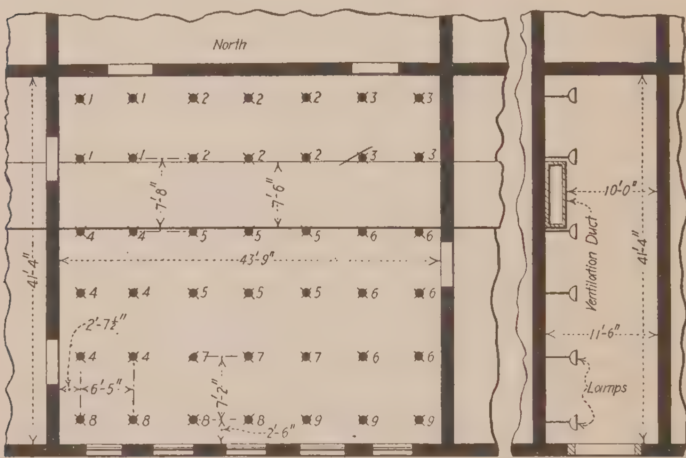
The spacing distance d having been ascertained, the designer should so lay out his area into squares or rectangles (Fig. 118) that the distance between lamps will be as nearly equal to the distance d as possible. Where there are different ceiling heights in the same room, the size of lamp is finally decided by the relation of spacing distances to the dimensions of the room. For the sake of standardization, the number of sizes of lamps used may be reduced to four as shown in the right-hand half of Table 239.

EXAMPLE OF APPLICATION OF THE WATTS PER SQUARE FOOT METHOD.—A draughting room (Fig. 122) has a ceiling 11 ft. 6 in. high and both it and the walls are light-colored. The area is 41 ft. 4 in. by 43 ft. 9 in., equalling 1,810 sq. ft. A ventilating duct causes an obstruction, as shown in Fig. 122, the bottom being 18 in. below the ceiling. An illumination of 7 ft.-c. is desired. Tungsten lamps in prismatic reflectors are to be used.

The effect will be best if all the lamps are mounted with the top of the

reflectors level with the bottom of the air duct. This gives a mounting height (which is always measured to the socket) of 10 ft. It is decided, upon referring to Table 239, to use 60-watt lamps, the watts per square foot being (from Table 250) 0.19 *watt per sq. ft. per foot-candle* × 7 *ft.-c.* = 1.3 *watts per sq. ft.* The ideal spacing distance, calculated out as explained, is 6 ft. 8½ in.

Laying out the lamps it is found that in a direction east to west, a spacing distance of 6 ft. 5 in. places them free from obstructions and leaves 2



I-Plan View II-Elevation

Note: All Lamps Having the Same Number are Controlled by One Switch

FIG. 122.—Example in laying out the illumination for an office room.

ft. 7½ in. at each wall. In the other direction the width of air duct is 7 ft. 6 in., which makes 7 ft. 8 in. the minimum distance apart that the two rows of lamps can here be spaced.

Thus placing one row of lamps as near as possible to each side of the duct and laying out the rest of the system, a convenient spacing distance is found by trial to be 7 ft. 2 in., and this figure is adopted, the row of lamps nearest the walls being 2 ft. 6 in. distant therefrom. The general spacing distance is 7 ft. 2 in. by 6 ft. 5 in. = 46 sq. ft. (Fig. 122), giving $^{60}/_{46}$ = 1.3 watts per sq. ft. for each lamp and for the whole area the figure is found to be $\frac{42 \times 60}{1{,}810}$ = 1.4 watts per sq. ft.

250. Watts per Square Foot Necessary to Produce an Intensity of 1 ft.-c. with Vacuum Tungsten Lamps.*—Table is com-

* National Electric Light Association.

piled on the assumption of an efficiency of 1 watt per candle. This is about the average efficiency for all of the commonly used sizes of vacuum tungsten lamps.

Lighting units	Area 30 ft. × 30 ft. or larger		Small areas	
	Light ceiling		Light ceiling	
	Light walls	Dark walls	Light walls	Dark walls
Prismatic	0.19	0.21	0.27	0.30
Opal, heavy density	0.40	0.21	0.26	0.29
Opal, light density	0.24	0.27	0.34	0.37
Semi-indirect	0.29	0.35	0.43	0.53
Totally indirect	0.32	0.37	0.50	0.62

Where the efficiency of the lighting unit to be used is other than about 1 watt per candle, the watts per square foot required will vary proportionately with the efficiency. The watts required per square foot varies directly as intensity in foot-candles.

251. Procedure in Designing a General Illumination Installation by the Watts per Square Foot Method.*—1. Measure the location, making a rough sketch of plan and elevation showing ceiling or roof trusses, positions of windows, obstacles which may affect the installation, present outlets and switching if any, and giving full dimensions.

2. Make a note of color and condition of walls, ceiling, furniture, machinery and equipment as well as the class of work carried on and the closeness of application required.

3. (*a*) Draw plans to scale.

(*b*) Decide on the lamp size and mounting height.

(*c*) Assume the watts per square foot to be used.

(*d*) Deduce the ideal spacing distance:

$$d = \sqrt{\frac{\text{wattage of lamp}}{\text{watts per square foot}}}.$$

(*e*) Lay out positions of lamps on the plan, to give regular spacing distances, installing a row within 2 ft. 9 in. of each wall if an office, and approximating, as near as possible, to the ideal spacing distance in both directions.

* Alex J. Airston, ELECTRIC JOURNAL.

(*f*) Make a tracing, from the plans, showing boundaries of the area and positions of lamps and old outlets, if any, also switching.

(*g*) Specify size of lamps and reflectors, mounting height and any other information deemed necessary for the assistance of the wiremen.

(*h*) Show control of lamps by numbering all lamps on one switch with the same number.

4. Check up the design at the actual location to see that each lamp is effective and free from all possible obstacles.

252. The Calculation of Illumination by the Point-by-point Method is a method based on the computation of the aggregate

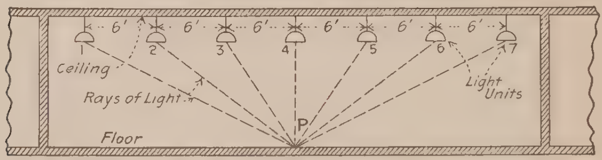


FIG. 123.—Illustrating the aggregate effect of several light units in illuminating one point.

intensity of illumination, at any designated point in an area, that is due to the several light units illuminating the area. It is a rather tedious method. It is not a direct method, hence is chiefly useful in checking an installation laid out in accordance with the "flux of light" method (243) to ascertain whether the lighting by that method is sufficiently uniform over the whole area. It is especially useful in designing outdoor illumination and for big shops and other large area propositions involving a small number of high-intensity units.

Figs. 123 and 124, *I*, illustrate the principles involved. It is evident from Fig. 123, that the illumination at *P*, or at any other point on the floor, is due to light coming from all of the light units. It is also evident from Fig. 124, *I*, that the illumination directly under lamp 11 or at any other point in the room, is due to light from all of the lighting units in the room. In using the point-by-point method, a certain number of

points or stations are arbitrarily selected at which it is desired to know the total illumination, as, for example, points *A* to *I* in Fig. 124, *I*. One point is considered at a time and the quota of intensity in foot-candles of illumination at that point, due to each of the lighting units, is then obtained from a table or by calculation.

Incandescent lamp and reflector manufacturers publish useful tables, too voluminous for insertion here, from which, for a given height and kind of lamp and reflector, the illumination

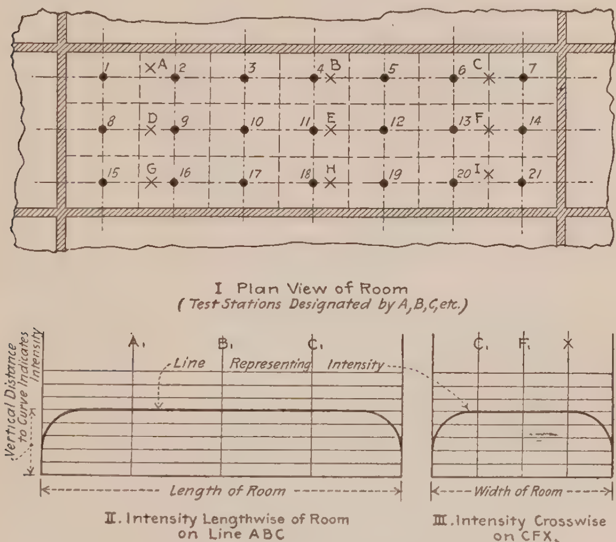


Fig. 124.—Illustrating point-by-point method.

value at given horizontal distances from the lamp can be read directly. These foot-candle intensities are then added together and their sum will represent the total illumination at the point.

Example.—Consider for illustration, Fig. 123, and assume that the seven lamps shown are the only ones in the room. It is desired to determine by the point-by-point method the illumination at point *P*.

Assume that for the mounting height illustrated and the size of lamp and type of reflector used the following illustrative values can be taken from a manufacturer's table.

Lamp No. 1 @ 18 ft.	0.01 ft.-c.
Lamp No. 2 @ 12 ft.	0.02 ft.-c.
Lamp No. 3 @ 6 ft.	0.20 ft.-c.
Lamp No. 4 @ 0 ft.	2.00 ft.-c.
Lamp No. 5 @ 6 ft.	0.20 ft.-c.
Lamp No. 6 @ 12 ft.	0.02 ft.-c.
Lamp No. 7 @ 18 ft.	0.01 ft.-c.
Total illumination at point *P*	= 2.46 ft.-c.

Then to correct for reflection, the value of 2.46 must be increased by a percentage from Table 256. Assuming very light ceiling and very dark walls, this percentage would be 30 per cent. Then: $2.46 \times 1.30 = 3.19$ ft.-c. which is probably somewhere near the correct value of the illumination at the point *P*.

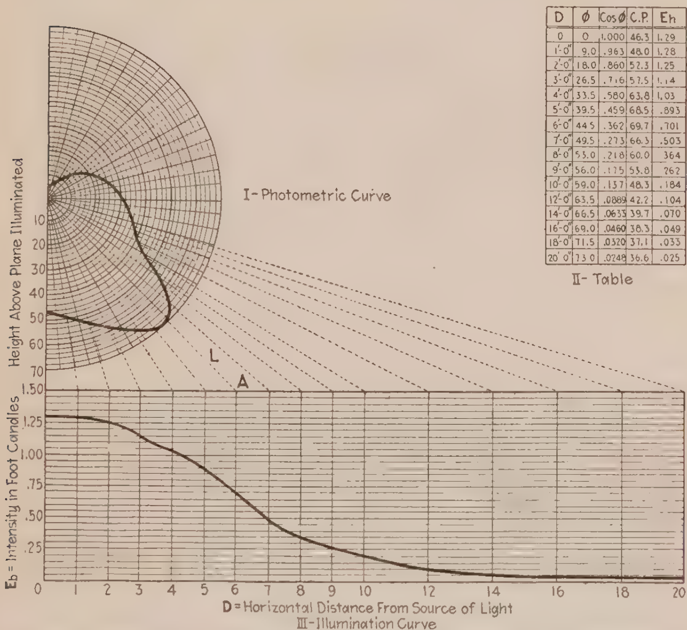
The total illumination is similarly obtained for each of the arbitrarily designated points. Then curves can be drawn somewhat as suggested at Fig. 124, *II* and *III*. These curves indicate (diagrammatically) the intensity of illumination in foot-candles at each point over a line drawn lengthwise of the room. The height of the curve above the base line at any point is proportional to the intensity at that point. In practice the curves are of course drawn to some scale so that the intensity at any point can be read directly. The contour of the curve indicates immediately whether or not the illumination, in a line lengthwise and that in a line crosswise of the room, is uniform.

253. Calculation of the Illumination Curve of One Lighting Unit. "Point-by-point Method."*—Having available the photometric distribution curve of a light unit (see Art. 97), an illumination curve can be derived, giving for some definite mounting height, the foot-candle intensities at various distances out from a point under the light unit. Fig. 125 illustrates to about two-fifths scale, a printed form which has been used by the Holophane Company, by means of which this

* Holophane Company.

curve of illumination can be derived very quickly and shown graphically. Then, with the illumination diagram at hand, it is possible to find the illumination at various typical points in any space under consideration with a given location of the light units, the illumination at each point being the sum of the illuminations from each separate light unit.

As shown in Fig. 125, the photometric curve, *I*, is first



D	ϕ	Cos ϕ	C.P.	Eh
0	0	1.000	46.3	1.29
1'-0"	9.0	.963	48.0	1.28
2'-0"	18.0	.860	52.3	1.25
3'-0"	26.5	.716	57.5	1.14
4'-0"	33.5	.580	63.8	1.03
5'-0"	39.5	.459	68.5	.893
6'-0"	44.5	.362	69.7	.701
7'-0"	49.5	.273	66.3	.503
8'-0"	53.0	.218	60.0	364
9'-0"	56.0	.175	53.8	262
10'-0"	59.0	.137	48.3	.184
12'-0"	63.5	.0889	42.2	.104
14'-0"	66.5	.0633	39.7	.070
16'-0"	69.0	.0460	38.3	.049
18'-0"	71.5	.0320	37.1	.033
20'-0"	73.0	.0248	36.6	.025

II- Table

FIG. 125.—Example of tracing illumination curves. (Holophane Co.)

plotted on the polar diagram, shown in the upper left-hand corner of the sheet. This is plotted to the largest candle-power scale possible and yet have the curve come within the limits of the diagram. Having determined the height above the plane for which the illumination curve is to be derived, the distances from the foot of the perpendicular through the light unit to the points for which the intensities are to be obtained

is fixed by the standard angles shown by the radial lines running from the polar diagram to the illumination diagram in the center of the sheet. For example, the point A is a fixed distance from the point under the light unit and this is equal to the mounting height of the light unit above the plane, since the line L is at 45 deg. Assuming then that the mounting height of the light unit is to be 6 ft., the distance OA, becomes 6 ft. and the other spaces are fixed at 1-ft. intervals up to 10 ft. and 2-ft. intervals between 10 and 20 ft.

From Art. 82 we have the formula:

$$(25) \qquad E_h = \frac{I}{H^2} \times (\cos \phi)^3 \qquad \text{(foot-candles)}$$

Having at hand a table of cubed cosines (Art. 254) for the different angles up to 90 deg. and since in any given problem H^2 is constant, it is necessary only to determine the different values of the apparent candle-power at the various angles.

On the diagram sheet it is necessary to carry back the radial lines for the 1-ft., 2-ft. intervals, etc., until they intercept the photometric curve, and read the candle-power at these points of interception. These are then entered in the table in the upper right-hand corner of the sheet as shown; multiplied by the proper value of the cosine cubed—since the angles are fixed on the diagram, the cosines do not vary; and the result divided by the square of the height, in this case, 36. The result is the horizontal illumination for the given point. This process is repeated for other points. Then a scale of foot-candle intensities is assumed for the diagram (Fig. 125, III) in the center of the sheet and the derived values of E_h are plotted as vertical distances, giving the resulting illumination curve for the unit in question mounted at the given height of 6 ft. above the plane to be illuminated. Then the intensity at any distance from the point directly under the light unit can be taken from this curve.

254. Table of Angles, Sines and Cosines.—Use in making calculations of illumination by the "point-by-point" method.

$\phi°$	$\sin\phi$	$\sin^3\phi$	$\cos\phi$	$\cos^2\phi$	$\cos^3\phi$	$\phi°$	$\sin\phi$	$\sin^3\phi$	$\cos\phi$	$\cos^2\phi$	$\cos^3\phi$
0	0.0000	0.0000	1.000	1.000	1.000	43	0.682	0.317	0.731	0.535	0.391
1	0.0175	0.0000	1.000	1.000	1.000	44	0.695	0.335	0.719	0.517	0.372
2	0.0349	0.0000	0.999	0.990	0.998	45	0.707	0.354	0.707	0.500	0.354
3	0.0523	0.0001	1.999	0.997	0.996	46	0.719	0.372	0.695	0.483	0.335
4	0.0698	0.0003	0.998	0.995	0.993	47	0.731	0.391	0.682	0.465	0.317
5	**0.0872**	**0.0007**	**0.996**	**0.992**	**0.989**	**48**	**0.743**	**0.410**	**0.669**	**0.448**	**0.300**
6	0.105	0.0011	0.995	0.989	0.984	49	0.755	0.430	0.656	0.430	0.282
7	0.122	0.0018	0.993	0.985	0.978	50	0.766	0.450	0.643	0.413	0.266
8	0.139	0.0027	0.990	0.981	0.971	51	0.777	0.469	0.629	0.396	0.249
9	0.156	0.0038	0.988	0.976	0.964	52	0.788	0.489	0.616	0.379	0.233
10	**0.174**	**0.0052**	**0.985**	**0.970**	**0.955**	**53**	**0.799**	**0.509**	**0.602**	**0.362**	**0.218**
11	0.191	0.0069	0.982	0.964	0.946	54	0.809	0.530	0.588	0.345	0.203
12	0.208	0.0090	0.978	0.957	0.936	55	0.819	0.550	0.574	0.329	0.189
13	0.225	0.0114	0.974	0.949	0.925	56	0.829	0.570	0.559	0.313	0.175
14	0.242	0.0142	0.970	0.941	0.913	57	0.839	0.590	0.545	0.297	0.162
15	**0.259**	**0.0173**	**0.966**	**0.933**	**0.901**	**58**	**0.848**	**0.610**	**0.530**	**0.281**	**0.149**
16	0.276	0.0209	0.961	0.924	0.888	59	0.857	0.630	0.515	0.265	0.137
17	0.292	0.0250	0.956	0.915	0.875	60	0.866	0.650	0.500	0.250	0.125
18	0.309	0.0295	0.951	0.905	0.860	61	0.875	0.669	0.485	0.235	0.114
19	0.326	0.0345	0.946	0.894	0.845	62	0.883	0.688	0.470	0.220	0.103
20	**0.342**	**0.0400**	**0.940**	**0.883**	**0.830**	**63**	**0.891**	**0.707**	**0.454**	**0.206**	**0.0936**
21	0.358	0.0460	0.934	0.872	0.814	64	0.899	0.726	0.438	0.192	0.0842
22	0.375	0.0526	0.927	0.860	0.797	65	0.906	0.744	0.423	0.179	0.0755
23	0.391	0.0596	0.921	0.847	0.780	66	0.914	0.762	0.407	0.165	0.0673
24	0.407	0.0673	0.914	0.835	0.762	67	0.921	0.780	0.391	0.153	0.0597
25	**0.423**	**0.0755**	**0.906**	**0.821**	**0.744**	**68**	**0.927**	**0.797**	**0.375**	**0.140**	**0.0526**
26	0.438	0.0843	0.899	0.808	0.726	69	0.934	0.814	0.358	0.128	0.0460
27	0.454	0.0936	0.891	0.794	0.707	70	0.940	0.830	0.342	0.117	0.0400
28	0.470	0.104	0.883	0.780	0.688	71	0.946	0.845	0.326	0.106	0.0345
29	0.485	0.114	0.875	0.765	0.669	72	0.951	0.860	0.309	0.0955	0.0295
30	**0.500**	**0.125**	**0.866**	**0.750**	**0.650**	**73**	**0.956**	**0.875**	**0.292**	**0.0855**	**0.0250**
31	0.515	0.137	0.857	0.735	0.630	74	0.961	0.888	0.276	0.0760	0.0209
32	0.530	0.149	0.848	0.719	0.610	75	0.966	0.901	0.259	0.0670	0.0173
33	0.545	0.162	0.839	0.703	0.590	76	0.970	0.914	0.242	0.0585	0.0142
34	0.559	0.175	0.829	0.687	0.570	77	0.974	0.925	0.225	0.0506	0.0114
35	**0.574**	**0.189**	**0.819**	**0.671**	**0.550**	**78**	**0.978**	**0.936**	**0.208**	**0.0432**	**0.00899**
36	0.588	0.203	0.809	0.655	0.530	79	0.982	0.946	0.191	0.0364	0.00695
37	0.602	0.218	0.799	0.638	0.509	89	0.985	0.955	0.174	0.0302	0.00524
38	0.616	0.233	0.788	0.621	0.489	81	0.988	0.664	0.156	0.0245	0.00383
39	0.629	0.249	0.777	0.604	0.469	82	0.990	0.971	0.139	0.0194	0.00270
40	**0.643**	**0.266**	**0.766**	**0.587**	**0.450**	**83**	**0.993**	**0.978**	**0.122**	**0.0149**	**0.00181**
41	0.656	0.282	0.755	0.570	0.430	84	0.995	0.984	0.105	0.0109	0.00114
42	0.669	0.300	0.743	0.552	0.410	85	0.996	0.989	0.0872	0.0076	0.0006

255. The Effect of Reflection Must be Considered in Making Calculations by the Point-by-point Method.—There is no way of accurately making a correction for the effects of reflection. A certain amount of light will be reflected from ceilings and walls—how much, it is difficult to ascertain. Table

256 gives constants that have been determined by experiments and that are ordinarily used, there being no better method readily available.

256. Reflector Factors for Point-by-point Method.*—The increases tabulated apply only to small or medium-sized rooms. In large spaces the effect of reflection will be less than that indicated. The tabulated values are for Holophane glass reflectors. The per cent. increase due to reflecton with opaque reflectors will be less than indicated in the table.

Color of ceiling	Color of walls	Increase over calculated illumination
Very dark	Very dark	0 per cent.
Medium	Very dark	15 per cent.
Medium	Medium	40 per cent.
Very light	Very dark	30 per cent.
Very light	Medium	35 per cent.
Very light	Very light	80 per cent.

257. In Calculating the Illumination of an Area Lighted by More Than One Unit by the Point-by-point Method, it must be remembered that the total illumination at any one point is due to a portion of the light from all of the units serving the area. Hence the foot-candle values can be read from a curve like that of Fig. 125 for each point at which it is desired to ascertain the total illumination. A separate foot-candles value must be taken from the curve for the portion of light contributed by each unit, this value being read from the scale E_h (Fig. 125) for the intensity indicated by the illumination curve at the distance H from the one light source then under consideration.

258. It Will Be Found That the Flux of Light and the Point-by-point Methods Often Give Different Results for the Same Problem.—There are several readily explainable reasons for this. Either should be considered merely as an estimating method.

* Holophane Company.

259. The Cost of Lighting Installation Is an Important Factor affecting the design. From a rough calculation, based on the total area of the room multiplied by the watts per square foot (Art. 250) and divided by the wattage of the lamp, an approximate figure of the number of lamps required is obtained. Expressed as a formula this statement becomes:

$$n = \frac{A \times w}{W} \qquad \text{(number of lamps)} \tag{42}$$

Wherein.—n = number of lamps, A = area in square feet w = watts per square foot. W = wattage of each lamp.

The cost per lamp installed complete is determined from experience and hence if the cost of the installation must be minimized the designer may be forced to reduce the watts per square foot in order to keep within a given appropriation.*

* ELECTRIC JOURNAL.

260. Data on Successful Carbon Enclosed Arc Lighting Installations.*—

	Clothing store	Weave room	Erecting room	Machine shop	Drafting room	Drafting room	Jewelry store
No. of sq. ft. in place lighted	4,000 ft.	14,400 ft.	281,600 ft.	42,250 ft.	6,275 ft.	5,690 ft.	4,000 ft.
No. of lamps used	12	50	200	42	27	24	6
Sq. ft. lighted per lamp	333	288	1,408	1,006	232	237	667
Sq. ft. lighted per amp. of current	55.6	88.6	227	162.2	30.9	59.2	133.3
Terminal-watts used per sq. ft	1.29	1.24	0.53	0.74	2.11	2.02	0.825
Kw. at terminals entire installation	5.16	17.85	148.80	31.25	13.22	11.52	3.3
Kw. at arc entire installation	4.62	12.28	99.20	20.80	12.42	7.68	2.4
Circuit	A.c. mult.	D.c. mult.	D.c. mult.	D.c. mult.	A.c. ser.	D.c. mult.	D.c. mult.
Volts terminals	104	110	120	120	76	120	110
Volts arc	72	80	80	80	72	80	80
Amperes	6	3.25	6.2	6.2	7.5	4	5
Actual watts per lamp	430	357	744	744	490	480	550
Enc. globe used	Opal	Wnod	Opal	Opal	Opal	Opal	Cone
Reflector used	C. diff.	Diff.	Mirror	Mirror	Inv. ceil	Diff.	Diff.
Height of arc from floor	9 ft. 6 in.	12 ft./15 ft.	46 ft.	47 ft.	9 ft.	15 ft.	15 ft.
Distance between lamps	14 ft./18 in.	24 ft. aprx.	32 ft./38 ft.	30 ft. 9 in.	15 ft.	12 ft. 25 ft.	16 ft. 25 ft.
Power-factor of lamp at terminals	0.69	....	....	....	0.83		
Height and style of ceiling	12 ft. steel White	Saw-tooth	Trussed	Trussed	12 brd. White	20 ft. trsd. White	16 ft. 10 in. Wht. plas.
Frequency	60 cyc.	....	....	....	60 cyc.		

* Westinghouse Diary.

SECTION 8

INTERIOR ILLUMINATION

261. Residence Lighting.—The illumination intensity ordinarily desirable in each room of a residence is given in the table of Art. 228. Ceiling fixtures in which the lamps hang at an angle should be avoided. As shown in Fig. 126, such fixtures tend to throw a strong light around the walls, and into the eyes of persons in the room, although the angle shown in

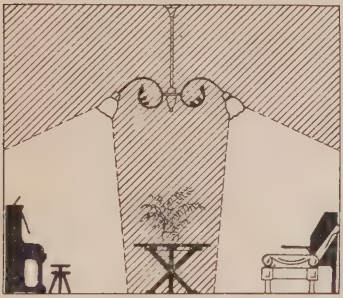


FIG. 126.—Effect of hanging residence lamps at an angle.

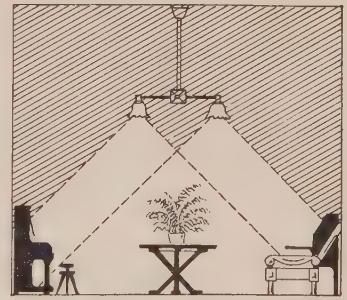


FIG. 127.—Effect of hanging residence lamps vertically.

Fig. 126 is the correct one when an incandescent lamp is completely enclosed in a ground glass or opal globe—an inefficient arrangement, but considered by some to be artistic. Lamps hanging pendant as in Fig. 127 distribute the light in useful directions. Diffusing globes or shades should be used on all lamps which hang low enough to fall in the line of vision. Indirect and semi-indirect reflectors (Fig. 77) have recently found a wide application in residence-lighting installations for which service they are eminently fitted. Bowl-frosted lamps should be used unless the lamp itself is completely shaded.

262. The Principal Considerations Affecting the Illumination of Any Interior Room or Area Are:* FIRST, the use of the room; SECOND, the selection of the kind of lamp best suited to the use of the room; THIRD, the proper quantity of light required for such use as the room may be put to, either specialized or general; FOURTH, the location of the outlets at such points that the light will best perform its office; FIFTH, the satisfaction of certain esthetic requirements which are inherent

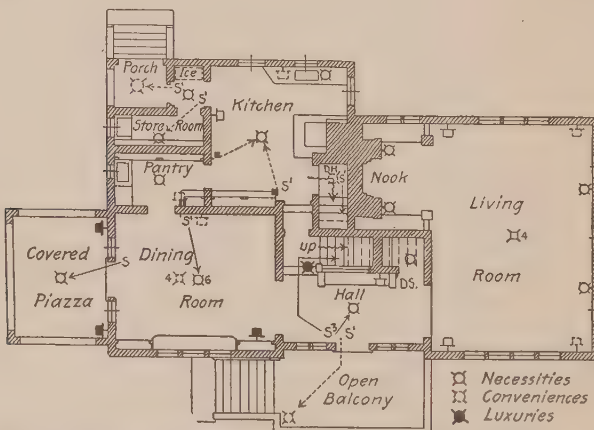


FIG. 128.—Typical wiring plan for first floor of residence showing outlets for lighting units and electrical devices.

in every lighting problem, and, SIXTH, the selection of a fixture of such a type and nature that it will properly perform its office as a light diffuser and will also be suitable esthetically with regard to its environments.

In homes, cost should not be the prime factor. The important point is quality of light or its effect on color. Adaptability of the height of the lamp to its surroundings is most important. Where the conditions require that the illuminating equipment should exemplify specific style and standards of taste, care should be taken not to multiply styles in a single room. The quality of light should ever be the dominant factor.

* David Crownfield, New England Ill. Eng. Soc., Boston, Jan. 9, 1911.

Figs. 128 and 129 show a typical wiring layout.* The outlets shown in solid lines indicate the equipment necessary in practically every installation. The outlets shown by dotted lines indicate additional lights, baseboard receptacles, and switches for convenience in using fans, table lamps, electric irons, and other household appliances. The solid black

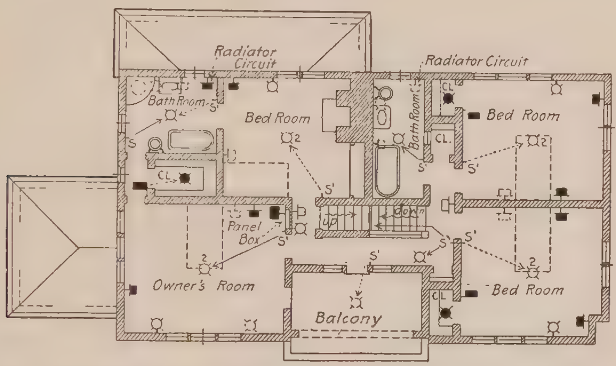


Fig. 129.—Typical wiring plan for second floor of residence. This is the second story of the building shown in Fig. 128.

outlets provide for what might be called luxuries: receptacles on the covered piazza for table lamps, automatic door switches in the bedroom closets, etc.

263. The Lighting of a Small Room.†—Comparative tests of illuminating equipments, conducted in a living-room 16.5 ft. long, 12.0 ft. wide and 8.5 ft. high. Color of ceiling, very light cream; walls covered with light-green rough paper. Red portières were placed over the door spaces and green window shades were drawn down over the windows during the tests In the geometrical center of the ceiling was placed a single lighting unit provided during all tests with a 160-watt tungsten lamp operated at 78.9 mean horizontal candle-power, equivalent to 773 lumens.

Observations of the illumination obtained over a plane 3.5 ft. above the floor were made with the lamp variously equipped, with the results shown in Table 264. The author expressed

* The Electric Equipment of the Home, National Electric Light Association.

† James R. Cravath, paper Chicago Sect. Ill. Eng. Soc., March 16, 1911.

the opinion that the semi-indirect system with opal reflector is far preferable to the opal ball arrangement, because it is not only easier on the eyes, but more efficient. He said that the semi-indirect system occupies a place midway between the direct system using opal reflectors and the indirect with opaque reflectors; it is not as comfortable as the indirect, and it causes more pronounced shadows. But it is more efficient and does not hide the source of light entirely, where some light is desirable for decorative effects.

264. Tests of Lighting Equipment in a Small Room.—

Lighting equipment	Minimum foot-candles	Average foot-candles	Lumens effective per 100 lumens generated
Bare lamp	0.698	1.597	40.9
Prismatic reflector, extensive, at ceiling	0.514	2.030	52.0
Opal reflector at ceiling	0.492	2.070	53.0
Indirect lighting, mirror reflector, below lamp	0.422	1.151	29.5
Semi-indirect, opal reflector, pointed upward	0.508	1.470	37.6
Roughened stalactite reflector at the ceiling	0.673	1.390	35.6
Opal ball, 8 in. at ceiling	0.528	1.310	33.7

265. Living-rooms.—The lighting of the living-rooms should in general be arranged with a view toward producing a comfortable and cheerful appearance rather than a high efficiency. The highly efficient types of reflectors are generally out of place in a living room as they do not provide sufficient general illumination to properly display the pictures and decorations, and therefore produce a gloomy effect.

266. Lighting the Kitchen and the Bedroom.—These are the two rooms in a house in which the arrangement of the lights is ordinarily most unsatisfactory. A single light or group of lights in the center of the kitchen usually compels the cook to work entirely in her own shadow, whether at the range, the sink or the kitchen cabinet or table. A couple of small bracket lights at the side of the room can usually be

arranged to satisfactorily light all three of these locations, and a third small light in the center of the room will give general illumination. The three need consume no more energy than a single larger unit, and will give much more satisfactory service. Similarly in a bedroom, one or two bracket lights should be provided at the dressing table, with a small unit in the center of the room for general illumination. The ordinary arrangements are usually satisfactory for other rooms, except that a single ceiling or table light in a library requires that all readers shall sit with their backs toward one another to secure satisfactory reading light. This can be obviated by using scattered ceiling lights, four or more, depending on the size of the room, or by side brackets with reflectors of a type which will shade the light from the eyes of those sitting across the room.

267. Store Lighting.—The object of the illumination in a store is twofold. Primarily, sufficient illumination must be provided to enable articles for sale to be seen plainly. But of almost equal importance is the advertising value. The lighting units must be so selected as to give a pleasing and cheerful appearance to the store as a whole, without glare. Stores may be divided into three classes: (1) The small store, in which efficiency is of first importance; (2) the large store, such as a department store, in which efficiency is necessary on account of the large areas to be lighted, but must be balanced by artistic appearance, the result being a compromise between the two; and (3) shops, large or small, in which the articles for sale are of a special type and the profits derived great enough that they can afford to have even the most inefficient system if it be sufficiently attractive or unique to attract customers. The general requirements which should be satisfied are outlined in the following paragraphs:

268. General Features of Store Lighting.—The intensity of illumination must be varied with the articles which are to be sold. Furniture requires well-diffused lighting of relatively low intensity. Colored dress goods, men's clothing, rugs and carpets, etc., require a high intensity. In many installations side light is very necessary and should be given especial at-

tention in selecting types of units, and reflectors. Cut glass and jewelry should be so lighted as to sparkle and glitter. This requires bare lamps and mirrored reflectors. Glare is to a certain extent, in this case, unavoidable, but the light units can usually be so located as to be out of the customer's range of vision, when he is inspecting the ware. Pictures require a high intensity, with the light units at such an angle that light will not be reflected from the surface of the painting, or from the glass, directly into the observer's eyes. Individual units or mirrored trough reflectors, with tubular tungsten lamps are ordinarily used.

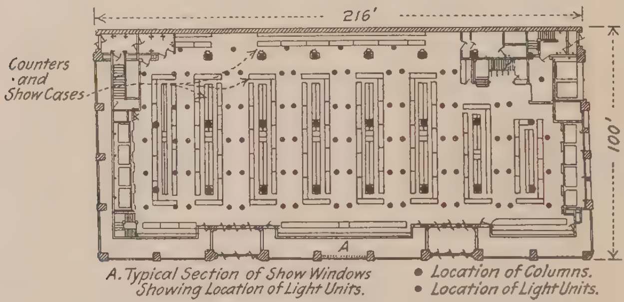


Fig. 130.—First floor plan of a department store showing lighting lay-out.

269. Uniformity in Store Illumination.—The location of the units and their distribution characteristics should be such that reasonably uniform illumination will result. It is very important to avoid having customers cast sharp shadows on the counters at which they are examining goods for sale. Typical layouts of the lighting of two floors of a department store are given in Figs. 130 and 131 which are described more in detail elsewhere. The lighting units are 250-watt tungsten lamps in prismatic satin-finished globes, suspended at a height of 12 ft., 6 in. above the floor. The distribution curve of these units is approximately similar to that usually known as intensive.

270. Attractive Appearance in Store Illumination.—The system of illumination must be unified, yet modified sufficiently to meet the individual requirements of the different counters

or departments. It is usually considered that the yellow color of the light from incandescent lamps lends a warmth and cheerful atmosphere to a store which is lacking in the colder white, or bluish-white light from arc lamps. This is largely a matter of taste. The consideration of appearance must be balanced against all others, as a small gain in artistic appearance is not worth a large sacrifice in other features.

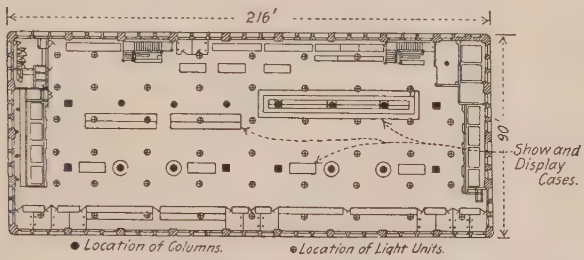


FIG. 131.—Showing typical arrangement of furniture and lighting units on the upper floors of a department store.

271. Color Value in Store Lighting.—In general, the color of the light should not depart too greatly from that of daylight, as a certain degree of color matching is always necessary. For very accurate color matching some of the large stores are maintaining small rooms from which all outside illumination is shut off, equipped with lamps, the light from which is so screened by carefully selected colored glass as to give exact daylight conditions. The lighting of many dry goods stores is designed on the basis that most of the better grades of material are to be worn under artificial light, and hence should be selected by a similar light, no attempt being made to reproduce daylight conditions. In any store it is not a good idea to mix the types of illuminants, as the combination of, say, the yellow light from incandescent lamps, with the purplish-white light from enclosed arcs, is displeasing.

272. Low Intrinsic Brilliancy Desirable in Store Lighting.—Glare must be avoided if possible, as nothing else so detracts from the appearance of a store. As it is ordinarily impossible to conceal all of the units, and indirect or semi-indirect lighting is frequently considered too expensive, or otherwise un-

desirable, it is often desirable to use deep-bowl reflectors or enclosing globes.

273. Maintenance of Store-lighting Installations.—Nothing so detracts from an otherwise pleasing lighting installation as dirty reflectors and burned-out lamps. Lighting installations require as regular cleaning as do windows. In most cities glassware should be thoroughly cleaned at least once a month. A careful system for regular inspection and cleaning has been initiated whereby all units in certain department stores are brushed with a stiff brush and cloth once every two weeks. Each unit is taken down and washed thoroughly once each month. The cost of cleaning, including labor and materials, is approximately $350 per year for approximately 1,000 units installed. Since the units are thoroughly cleaned once a month, the cost of cleaning per unit will be approximately 3 cts., which includes one dusting and one washing. A fair division of this cost would be 0.5 ct. per unit for dusting and 2.5 cts. for thorough cleaning. Under such a system the illuminating efficiency is maintained at a practical maximum. It is probable, however, that in other places where dirt and dust conditions are not as severe, the cleaning might be done at less frequent intervals.

274. The Lighting of a High-class Department Store.*—The building is fourteen stories high, including the basement and the attic. The ground floor (Fig. 130) covers a space 100 ft. by 216 ft. and each of the remaining floors (Fig. 131) 90 ft. by 216 ft. The inside area of the first floor is approximately 20,370 sq. ft., and that of the remaining floors 17,850 sq. ft. each. The outside of the building is finished in white terra-cotta; the interior, including the fixtures, is in mahogany. The lighting equipment throughout was changed to that enumerated by floors, in the following paragraphs.

In the basement delivery room clusters were replaced by eighteen 60-watt clear tungsten lamps in enameled steel reflectors.

On the main floor (men's furnishings, jewelry, stationery, trimming, etc.) the ornamental arc and incandescent fixtures

* ELECTRICAL WORLD.

were adapted to reflector-ball units of special design, with upper prismatic reflectors resting on stalactite-shaped blown globes, the whole satin-finished. By varying the lamp position, extensive, intensive and focusing distributions could be obtained, the intensive being adopted. Each of 16 arc lamps were replaced by a 250-watt clear tungsten unit. The five four-lamp pillar brackets and the 34, two-lamp fixtures were replaced by 25-watt tungsten lamps in decorative shades.

For the second floor, where bedding and yard goods are sold, the equipment formerly consisted of 53 inclosed arc lamps, with opal outer globes. Fairly high illumination is required here for matching dress goods. Each arc lamp was replaced by a 400-watt clear tungsten lamp placed inside a 14-in. two-piece diffusing glass bowl. The unit consists of a clear stiletto-prism reflector mounted over a satin bowl, in a verde-antique fixture.

On the third floor, where ladies' suits, waists and furs are sold, 51 arc lamps were replaced by 250-watt tungsten lamps, and in the side brackets 25-watt tungsten lamps were used.

On the fourth floor in the millinery department, 12 arc lamps were replaced by 150-watt clear tungsten lamps in semi-indirect fixtures of Louis XIV ornamental design to conform with the room. The rest of the floor is lighted by thirty-three 250-watt units like those on the third story.

On the fifth floor, where china, bric-à-brac and rugs are sold, of the 50 arc lamps 25 were replaced by 150-watt units and 25 by 250-watt clear tungsten lamps.

Sixth Floor.—Mission furniture, wall paper, draperies, art goods and the ladies' parlor. For the general illumination 30 arc lamps were replaced by tungsten units as on the third.

Seventh Floor.—Forty-five arc lamps formerly lighted the men's clothing department on the seventh floor, where also are located the general offices. Of these 36 were replaced by 400-watt and nine by 250-watt clear tungsten units. A high intensity is needed here, as on the second floor, on account of the dark colors of the goods displayed.

Remaining Floors.—The installations already cited exemplify the general practice followed on the other floors, except

in the dining-room where 71 six-lamp clusters were replaced by 150-watt tungsten units.

275. Rug-rack Illumination with Trough Reflectors.*—Continuous reflectors have been recommended (Fig. 132) for this work as it is claimed that the distribution therefrom is better and that the installation is simpler. If the arms reach to within a few inches of the ceiling the reflector is readily installed on blocks fastened to the ceiling. If the ceiling is some distance from the top arms, the reflector is suspended on hangers or chains. The reflectors should be so mitered that they will conform to the sweep of the arms. With a properly designed

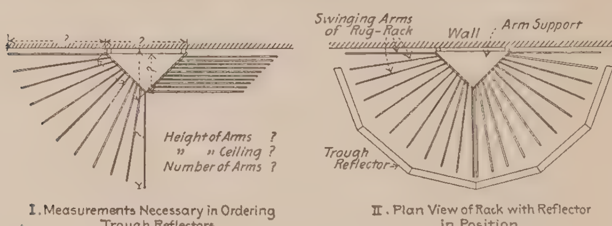


FIG. 132.—Trough rug rack reflector.

reflector an evenly diffused light can be thrown over the entire surface of the rug with the arms in any position. The measurements suggested in Fig. 132, *I*, are usually required when ordering a reflector of this kind.

276. Rug-rack Lighting in a Large Department Store.—Twenty-five outlets are provided on the circumference of a semicircle, the radius of which was approximately 2 ft. greater than the maximum swing of the rack arms. Outlets were located at centers 2 ft. 6 in. apart. Wiring was run in metal molding and small porcelain receptacles having a metallic head for use with shade holder were used. Each outlet was equipped with one 40-watt clear tungsten lamp and a 30-deg. angle-steel reflector having an aluminumized interior surface mounted on the ceiling in a pendent position.

277. The Requirements for the Correct Illumination of Jewelry Stores† are quite complex. Much of the pleasing

* I P. Frink Co.

† E. M. Smith, ELECTRIC JOURNAL.

effect of jewelry is produced by the reflection of light from polished surfaces or facets. The predominating policy of jewelry stores has been to use large numbers of small, high-intensity units. These are seldom properly placed and shaded. Usually the result is a rather gaudy, glaring appearance. While one prime requirement—that of having plenty of light—has been satisfied, other features have not. The general illumination should be diffused but not of sufficient intensity to detract from the effect of the special lighting and it should not be too conspicuous. Show-cases should be lighted brilliantly, but from concealed light sources. Best results when inspecting jewels are secured by light from so-called "point light sources." Special attention should be given to the proper illumination of the display surface, both as to the source of light and its color effect.

278. An Example of Jewelry-store Illumination is shown in Fig. 133. General lighting is afforded by three 500-watt clear

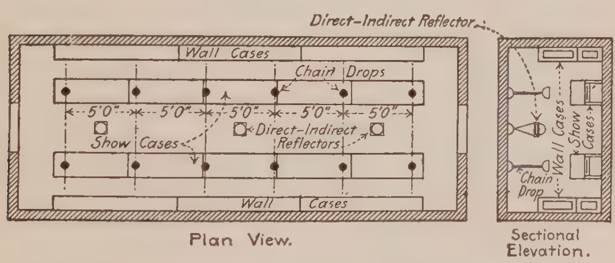


FIG. 133.—An example of jewelry-store lighting.

tungsten lamps equipped with direct-indirect (semi-indirect) reflectors. The ceilings are of white metal. The illumination is soft and restful to the eye. Since jewelry cannot be displayed to advantage under a diffused light, 12 chain drops, 5 ft. apart, were placed directly over the show-cases. These are equipped with 60-watt clear tungsten lamps and focusing type Holophane reflectors. Over these reflectors are metal caps, spun to conform with the shape of the reflectors and lined with light blue enamel which accentuate the blue from the lamps, thereby approximating daylight color effects while still retaining the advantage of good reflection. The metal caps

also serve to minimize the effect of glare in the room. The side wall cases are lighted by five 35-watt tungsten tubular lamps in each section. The light sources are hidden from direct view, while an average intensity of 6 ft.-c. is obtained.

279. Requirements of Show-window Lighting.—Successful show-window lighting is characterized by two features. *First*,

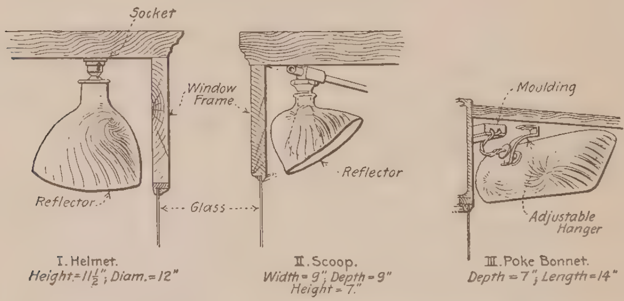


FIG. 134.—Specially designed silvered glass show-window reflectors.

the window should be so brilliantly lighted as to attract the attention of the passer-by to the goods there displayed. The goods must form the attraction, however, and not the lights. *Second*, the goods themselves should be so illuminated that they show at their best when the closer scrutiny of the

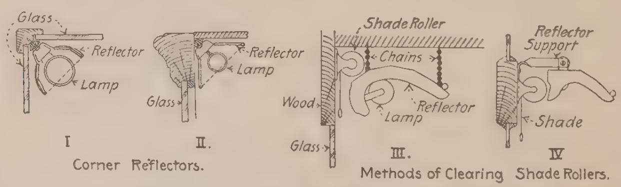


FIG. 135.—Some methods of supporting trough window reflectors.

passer-by has been drawn to them. A suitable reflector is always necessary to secure efficiency of illumination and it should be of such a design as to completely hide the light source. Special reflectors (Fig. 134) will all give good results if suitably chosen for the character of work. Special reflectors must be hung according to the maker's specifications. Fig. 135 illustrates some typical methods of supporting trough

window reflectors. Standard reflectors, if used, must be hung at such an angle that the entire floor, and as much of the back and side walls of the window as desired are uniformly lighted, and that very little of the light reaches the sidewalk, because the window appears much brighter with a dark sidewalk.

280. Show-window Lighting.*—In the average-sized window, tubular lamps will, particularly in confined locations, give excellent results when used with properly designed reflectors on account of their special adaptability to limited space conditions. Reflectors with standard-base lamps should be used in unusually high windows, and in windows unusually deep, such as found in furniture stores. They may also be used in some cases where the windows in question are situated next to a store front on which there is installed a mass of exposed lamps, the glare of which makes it necessary to utilize an excessive illumination to make the window under consideration appear properly lighted. With correctly designed reflectors there are few windows that require more light than that given by 40-watt lamps spaced 8 in. apart. With this equipment somewhat more than 8 to 12 ft.-c. on the floor of the windows from 8 to 12 ft. high can be developed. If the window is not boxed in, the reflector should be provided with a shield to screen the lamps from the store. If the upper part of the window back is glass, or the window is backed with mirror, the reflector should also be designed with a shield to prevent back reflection.

281. Number of Lamps Required per Front Foot for Window Lighting.†—The number of lamps per front foot of window or the watts per front foot required for good window illumination, depend very much on the location of the show window, whether it is on a brilliantly lighted street and in a city where a great deal of light is commonly used in show windows, or whether it is in a town where only a limited amount of show-window lighting is common. For example, in a small country town a single reflector may give a better illumination of a window with an 8-ft. frontage than is common among the other windows in

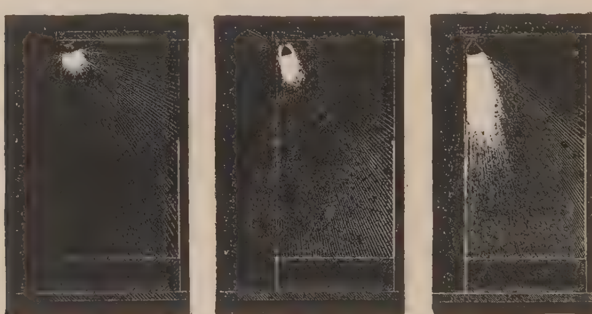
* I. P. Frink Catalog.

† National X-Ray Reflector Company.

the town. In large cities where dark dry goods and men's clothing are displayed, some merchants consider that a window cannot be too brilliantly illuminated.

On account of the efficiency of properly designed reflectors (because of the fact that they confine and direct nearly all of the light where it is wanted) it is of course not necessary to use as many lamps where the reflectors are properly designed as where they are not. Where reflectors are designed for relatively large lamps (100 and 60 watts), the lamps can be spaced some distance apart and still give good results. Some splendidly lighted show windows in large cities have 100-watt lamps spaced 18 and 24 in. apart. In the small towns where lower standards of illumination prevail, this spacing can be safely increased to 36 in. or more.

282. Some Common-sense Facts Regarding Window Lighting* (see Fig. 136).—A good way to "blind" the prospective



I. II. Effect with Improperly Selected Reflectors. III. Effect with Proper Reflectors.

FIG. 136.—Illustrating good and bad window lighting.

customer, so he cannot see the goods on display in the window, is to locate exposed lamps around the window borders or to suspend them from chandeliers or so install them in the top of the window that his eye cannot escape them. The light must come from in front of the goods in order to avoid shadows. If the lamps are placed in the middle of the show-window ceiling, the front of goods displayed in the front of the window will

* National X-Ray Reflector Company.

be in darkness, because of the shadows. Strange to say, many do not consider this. If the display is altogether on the bottom of the window, as in the case of a jewelry store, this shadow effect is unimportant. In the clothing or dry-goods store window, it is vital.

Carrying out this principle that light must be thrown on the goods from the front of the window in order that passers-by may see no shadows on the goods, practically means that the lamps must be placed high up in the window next to the window pane, because there is no other place where they can be located to throw the light in the proper direction and keep the lamps out of the ordinary range of vision.

283. One Frequent Defect of Window Lighting Is Flatness, or Lack of Perspective.—Sharply defined shadows, providing they are not too deep, make the goods stand out in perspective and add greatly to the attractiveness of the illumination. The desired shadow effect may be obtained by massing a considerable proportion of the light units used in either the right or the left upper front corner of the window. In order to prevent the shadow effect from being too deep, the remaining light units must be properly spaced.

284. Glass Panels at the Back of Show Windows near the tops may cause reflection into the eyes of observers as indicated in Fig. 136A. However, as indicated by the illustration, this defect can be eliminated through the provision of a properly designed reflector.

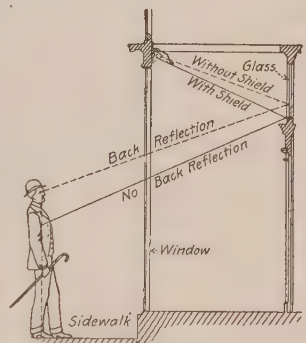


FIG. 136A.—Indicating how glass panels in show windows may reflect into the eyes of the observer.

285. Illumination of Show Windows with Wiring in Molding (see also section on *Interior Wiring* in the author's AMERICAN ELECTRICIANS' HANDBOOK).—The molding is attached to the upper horizontal part of the window frame.* "Aluminum

* L. P. Auerbacher, ELECTRICAL CONTRACTING.

shades requiring no shade holders can be used. The reflectors should not be spaced more than 12 in. on centers, and if dark goods are shown or if the window is deep or high, not more than 6 in. or 8 in. If the window frame is not wide enough to conceal the lamps a curtain dropping possibly 8 in. from the top should be used. Or better still, a dark strip 8 in. wide may be painted on the window at the top. This strip may also be used as a transparent sign. This method of window lighting has the advantages of low first cost and rapidity of installation. Where mirror troughs are used they must be made to fit the window and, if run on the side window frames, a template of the miter at the angle between the front and side windows must be sent to the manufacturer. This consumes time and involves the risk of measurement mistakes and breakage in transit."

286. In Lighting Counter and Display Cases the same rule is followed as with show-window lighting, viz.: throw the light on

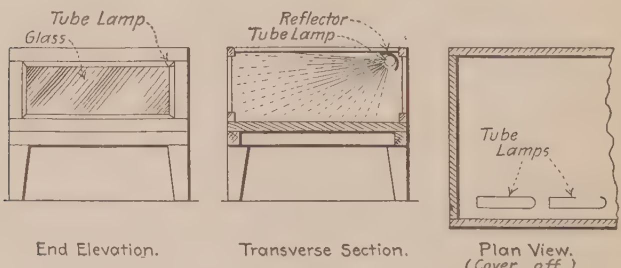


FIG. 137.—Example of counter-case lighting.

the goods displayed and not into the eyes of the observer. If the glare from the lamps reaches the observer's eyes he is partially blinded and the result desired is not accomplished. Fig. 137 shows a typical method of lighting a counter case and Fig. 138 that for a display case. Tube tungsten lamps are to be preferred and they should be equipped with proper—continuous if possible—reflectors. Ordinary pear-bulb lamps can be used with suitably designed reflectors but the tube lamps give more effective results and constitute a neater installation,

and furthermore the heating of the show-case glass work is equalized, minimizing its breakage.

287. The Wattage Required to Properly Illuminate Display and Counter Cases varies with conditions. Experience provides the only rules for this work as conditions, such as reflection from the glass work and mirrors, render calculation useless. As a general proposition, the illumination in cases

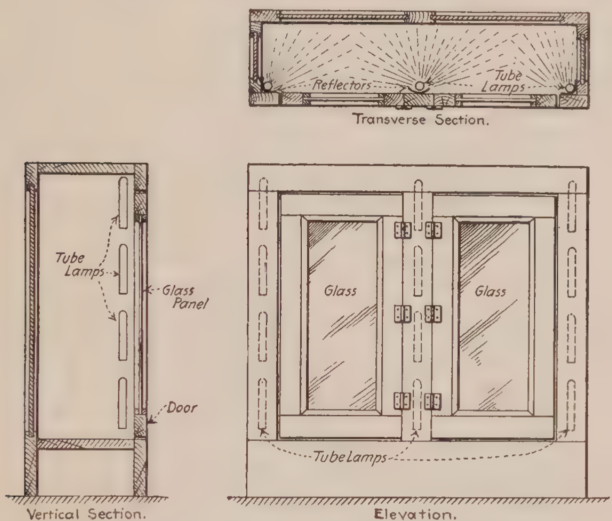


FIG. 138.—Example of display-case lighting.

should be double that in the store.* In an 8- to 12-ft. show case, 100 watts (ordinary show-case reflectors and tungsten lamps) will give excellent results with an average illumination of something more than 7 to 8 ft.-c. With mirror-lined reflectors, the same intensity may be maintained, with the same wattage, in a 12-ft. case.

288 Office Lighting.†—In general, it is more economical and satisfactory to provide general rather than specific illumination in offices containing a number of desks. The illumination desirable may be ascertained from Table 228 and the number of units necessary to provide this illumination can be found

* H. W. Johns-Manville Co.

† C. E. Clewell, ELECTRIC JOURNAL.

by the method given in a preceding paragraph (Art. 248). In locating the lights, the outer row should not be placed more

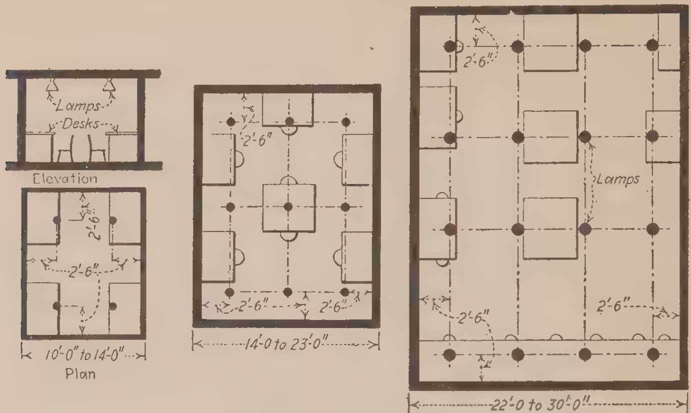


FIG. 139.—Good spacings of ceiling lights for offices. (Adapted from C. E. Clewell in ELECTRIC JOURNAL.)

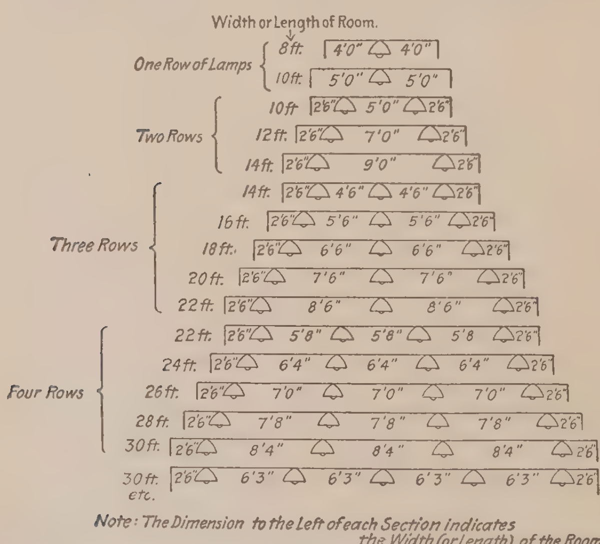


FIG. 140. Chart showing spacing distances of lamps for offices of various sizes. (C. E. Clewell, ELECTRIC JOURNAL.)

than 2½ ft. from the wall, to avoid shadows on desks placed about the walls. Fig. 139 shows good spacings of lamps for

offices of various sizes and of ordinary height. Fig. 140 gives, in the form of a chart, spacing distances which have been found by experience to be satisfactory with different ceiling heights. As in industrial lighting, the cost of illumination is usually so small a percentage of the salaries of the men in an office that a very small increase in their efficiency, due to less eyestrain, fewer headaches, etc., will more than pay for even an extravagant lighting system.

289. Specific Desk Lighting (Fig. 141) should as a general proposition be avoided. This is particularly true in large

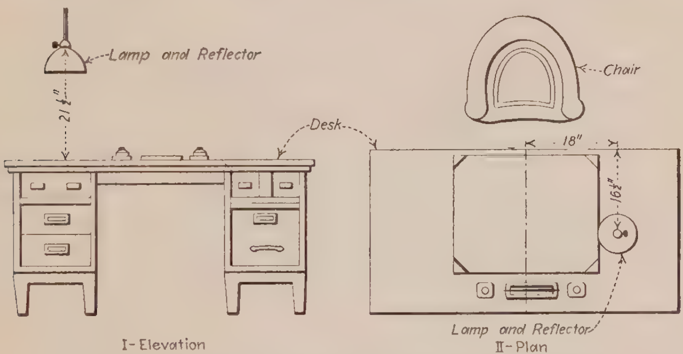


Fig. 141.—Proper method of hanging a desk lamp.

offices where a number of desks are located. A much better plan is to provide, as outlined under *Office Lighting* (Art. 288) a general illumination sufficiently bright to render individual desk lighting unnecessary. Specific desk lighting should, generally, be restricted to cases where one or two desks are located in an office chiefly used for other purposes, which permit of a comparatively low degree of illumination.

Note.—Do not locate the desk light too close to the work. The light unit for a desk should be hung 21 to 24 in. above the desk, about 16 to 18 in. from the front of the desk and about 18 in. to the left of the center. The lamp should be shaded from the line of vision by a bowl type of reflector—preferably one which is opaque. Too much light is as objectionable as too little. A 25-watt tungsten lamp provides ample light when located as suggested. A polished reflector is intolerable as the streaks produced are very trying to the eyes.

12

290. Wiring for Office and Industrial General Illumination Systems* should be arranged so that a minimum number of conductors will cross the girders. Consider Fig. 142, *I* and *II*, in which each group of lamps enclosed in a dotted-line rectangle comprises a circuit controlled by a separate switch. At *I* the circuits straddle a girder, while at *II* the arrangement is such that the branch circuit wires do not cross the girders. The latter arrangement involves minimum installation expense.

291. Switches Controlling General Illumination Systems* should be so arranged that the lamps nearest the windows can be controlled independently of the others. This is desirable so that it will be possible to use only the lamps in toward the middle of the room at times when there is enough natural light for sufficient illumination near the windows but not enough for the balance of the room. Fig. 143 illustrates the idea. With the arrangement of *I* the lamps near the windows are on separate circuits, hence can be extinguished when there is sufficient daylight to render them unnecessary and the lamps toward the center of the room are independently controlled. With the arrangement of *II* the lamps must either be all on or all off. Ceiling pull switches can be used with economy in many instances.

292. Industrial Lighting.—General illumination of the intensities given in Art. 228 is recommended for practically all manufacturing establishments, with added specific illumination at points where higher intensities are needed. In laying out the general illumination the "flux of light" method of Art. 243, is ordinarily used. The spacing of the lights often requires considerable care to avoid shadows. Units near large pieces of machinery should be placed first, to cast as little shadow as possible, and the others spaced at proper distances from them. High ceilings require large units, which are spaced at considerable distances apart. If there are no cranes, the units may be hung relatively low. Where there are cranes, the lights must be located above them. In such cases, bracket lights along the side walls, placed high enough to avoid

* Clewell.

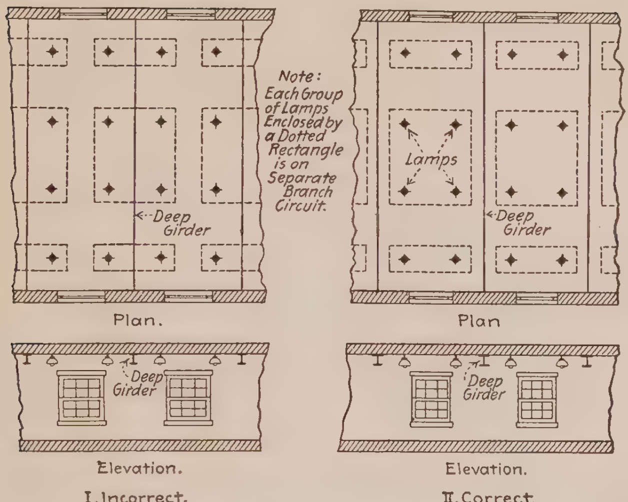


FIG. 142.—Illustrating correct and incorrect circuit grouping on a ceiling cut by beams.

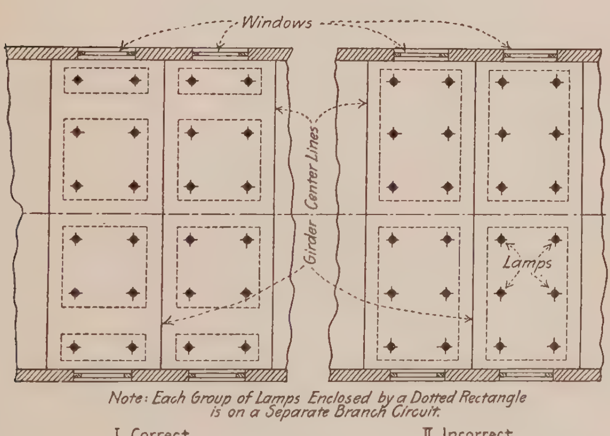


FIG. 143.—Correct and incorrect lamp grouping with respect to switch control.

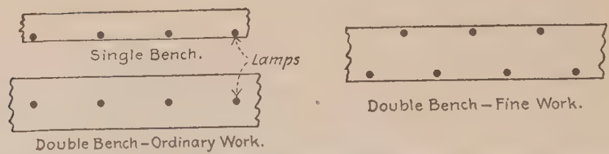


FIG. 144.—Good locations of lights for factory-bench lighting.

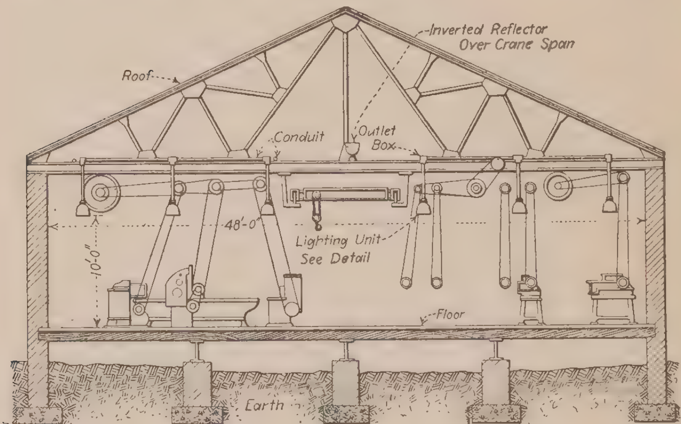


FIG. 145.—Cross-section through machine shop, plan view of which is shown in the following illustration.

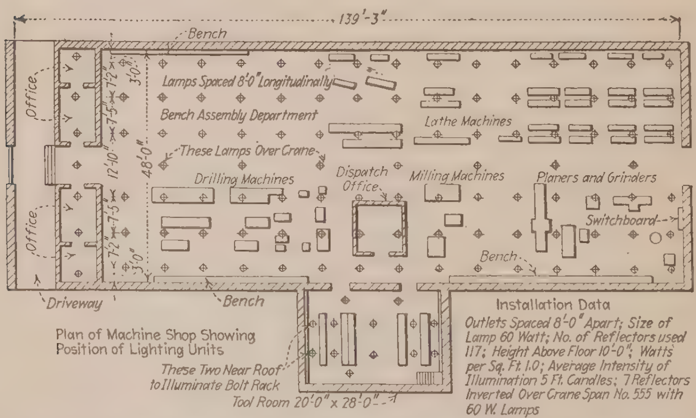


FIG. 146.—Lighting plan using metal reflectors for machine shop, College of Engineering, University of Illinois (National X-ray Reflector Company, Chicago, Ill.). See preceding illustration for sectional view of this shop.

glare, frequently add greatly to the efficiency of an installation. Flame arc lamps and mercury vapor lamps are the large units in most common use under certain conditions, the color of the former being especially suitable for foundries, steel mills, etc., on account of its ability to penetrate steam and smoke.

For medium and low ceilings the tungsten lamp with glass or metal reflectors has come into almost universal use. In general, the selection of lamp sizes, spacing distances and type of reflector is the same as for any other type of installation (Art. 231 to 240). Where considerable side light is required, as for instance on a milling machine, a reflector should be chosen with a much more broadly distributing characteristic than is normally required for the spacing distance selected. It is important that incandescent lamps and reflectors should be cleaned at regular and frequent intervals. In large installations, it has been found much cheaper to replace the reflector, and do the cleaning at a centrally located wash-room, than to attempt to do it at the location where the reflector is being used.

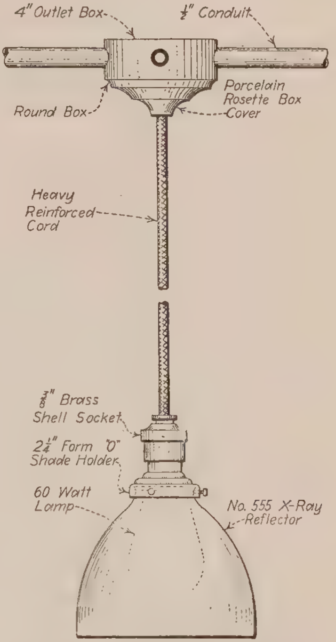


FIG. 147.—Showing arrangement of lighting unit used in illuminating the University of Illinois Machine Shop.

Where specific lighting is desirable as for lathes, punch presses, drill presses and other machine tools, the lamp should be so placed that the light falls on the work only, and not in the operative's eye. Shades should be provided for all specific lights. Fig. 144 shows good location for lights for bench lighting where the intensity produced by the general lighting is too low for the work required at the benches. Figs. 145, 146 and

147 show an example of machine-shop lighting with metal-reflector-and-tungsten-lamp units.

292A. Lighting Code for Factories, Mills and Other Work Places, Pennsylvania Department of Labor and Industry. General Requirement (*Rule I*).—Working or traversed spaces in buildings or grounds shall be supplied during the time of use with artificial light in accordance with the following rules whenever natural light falls below the intensities specified in Rule II.

Intensity Required (*Rule II*).—The desirable illumination intensity to be provided and the minimum intensity which shall be maintained are shown in the following table:*

No.	Character of area illuminated	Foot-candles, illumination	
		Minimum	At the work. Ordinary acceptable practice
1	Roadways and yard thoroughfares.....	0.05	0.05– 0.25
2	Stairways, passageways, aisles, storage spaces..........................	0.25	0.25 – 0.50
3	Rough manufacturing operations such as foundry work, rough machining, rough assembling, rough bench work..	1.25	1.25– 2.50
4	Fine manufacturing operations such as fine lathe work, pattern and tool making, light colored textiles, tobacco manufacture.......................	3.50	3.50– 6.00
5	Special cases of fine work such as watch making, engraving, drafting, dark colored textile.....................	5.00	10.00–15.00

Uncertain cases and intermediate requirements are to be left to the judgment of the State Industrial Board.

* This rule is intended to provide adequate illumination at the work. For purposes of measurement a horizontal reference plane 30 in. above the floor is to be taken, and a properly standardized portable photometer or illuminometer used. For purposes of very rough estimate it may be stated that, with a good overhead system of lighting, one candle power (spherical) per square foot of floor area should produce an illumination intensity of about three foot candles.

SHADING OF LAMPS (*Rule III*).—Glare either from the lamps or from unduly bright surfaces produces eye-strain and increases accident hazard. Exposed bare lamps shall not be used except when they are out of the ordinary line of vision; lamps should be suitably fitted to minimize glare.

DISTRIBUTION OF LIGHT ON THE WORK (*Rule IV*).—Lamps shall be so arranged as to secure a good distribution of light on the work, avoiding objectionable shadows and sharp contrasts of intensity.

EMERGENCY LIGHTING (*Rule V*).—Emergency lighting shall be provided in all work space, aisles, stairways, passageways, and exits; such lights shall be so arranged as to insure their reliable operation when through accident or other cause the regular lighting is extinguished.

SWITCHING AND CONTROLLING APPARATUS (*Rule VI*).—Switching or controlling apparatus shall be so placed that at least pilot or night lights may be turned on at the main point of entrance.

293. Comparison of Arc and Tungsten Lighting in a Shop Building.*—The illustrations and graphs of Fig. 148, show the arrangement and illumination distribution secured by lighting a shop building with inclosed arc lamps and with tungsten units, the wattage totaling the same in each case. In addition to the arc lamps, the original installation was supplemented by about 50 drop lamps over the individual machines. These were found unnecessary when the tungsten units were employed. It should also be noted that in addition to producing a much higher average intensity of illumination, the distribution from the tungsten units is more uniform. The illumination intensity from the arc installation, on the other hand, varied between 0.17 and 4.45 ft.-c. at different locations all of which should have had equally good illumination.

294. Data on Lighting a Shop Building with Tungsten and with Carbon Arc Lamps.†—(See Fig. 148.)

* ELECTRICAL WORLD.
† ELECTRICAL WORLD, Feb. 22, 1913.

Characteristics of the two systems	220-volt arc lamps	110-volt tungsten lamps
Total number of lamps required	16	80
Height of lamps above floor, feet	10	12.5
Height of test plane, feet	3.5	3.5
Lamps per bay	1.25	4
Watts per lamp	750	150
Area of bay (12.5 ft. by 49.5 ft.) square feet	618	618
Watts per square feet	0.97	0.97
Annual cost for equal illumination	$3,890	$1,108

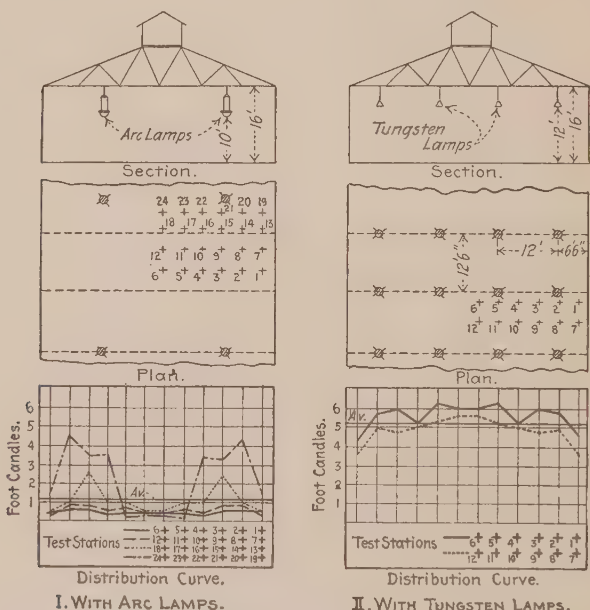


FIG. 148.—Comparison of mill illumination with tungsten and arc lamps.

295. A Typical Example of Factory Lighting* is shown in Fig. 149. The building contains more than 225,000 sq. ft. of floor space and in it have been installed over 3,000 tungsten lamps. This building (a plan of which is shown in Fig. 149) consists of eight floors, mostly devoted to the manufacture of small ma-

* Clewell.

chine parts. The walls are light in color and the building has light ceilings. The height from floor to ceiling is 13 ft. 6 in. and the building is divided into bays of 16 by 70 ft. The work may be classified into (1) bench work, requiring in many cases good illumination on vertical surfaces; (2) machining work, where line shafting and belting form an obstruction to the light; (3) assembly work, often performed on the floor where illumination on the horizontal, inclined and vertical surfaces is imperative; and (4) a storage warehouse, where a low intensity is sufficient.

The ceilings are of wood and hence wooden molding was advantageously used. Switches were placed on central columns,

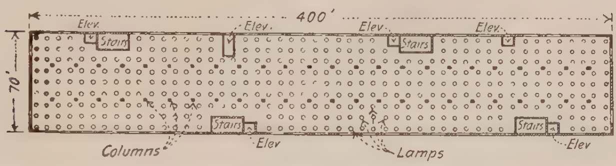


FIG. 149.—Showing tungsten general illumination in a large factory.

on the same side of the aisle throughout and on the same relative side of each column wherever possible. In feeding the switches, iron conduit was run down the concrete columns and iron outlet boxes served the double purpose of supports for the snap switches and of wall receptacles as outlets for extension lines when required. A study of the conditions to be satisfied in lighting this building brought out the following facts.

(*a*) SIZE OF LAMPS.—One hundred watt lamps seemed the best average size. At least two intensites were found advisable, one somewhat high for detail and machine work, and a lower intensity for general assembly work.

(*b*) MOUNTING HEIGHT.—Various mounting heights tried. It was found very desirable to mount the lamps as close to the ceiling as possible, to minimize glare.

(*c*) NUMBER OF LAMPS PER BAY.—The general scheme of installing 18 lamps per bay seemed best.

(*d*) ARRANGEMENT OF SWITCHES.—The switching of six lamps per circuit, while possessing some good features, did not

seem a sufficient subdivision. At times the work directly next to windows, was sufficiently lighted by daylight, while the work under the second row of lamps was insufficiently lighted. This led to the conclusion that the lamps next to the windows in each bay should be on one switch, and four lamps per switch in general seemed a better arrangement than six.

(*e*) DEPRECIATION DUE TO DUST.—It was found after several months of service, during which time the reflectors were allowed to remain uncleaned, that tests on each of the reflectors before and after cleaning indicated about the same degree of reduction in efficiency. It was noted, however, that reflectors located near belting became covered with dirt in very much less time than when the lamps were in a clear open space.

(*f*) INTENSITY OF ILLUMINATION ON OTHER THAN HORIZONTAL SURFACES.—While the ratio of spacing distance to mounting height of the lamps called for a concentrating reflector, a distributing reflector was essential for the purpose of providing the necessary side light (Art. 237). An intensity of about 2 ft.-c. on the sides of machines seemed to be sufficient.

(*g*) BOWL-FROSTED VS. CLEAR LAMPS.—Bowl-frosted lamps proved not so desirable as clear lamps, due to the more rapid effect of dust and dirt on the frosting than on clear glass. This effect is, of course, particularly noticeable in factory work.

(*h*) METAL VS. GLASS REFLECTORS.—Metal reflectors in these locations were far inferior to glass because of the fact that no light passes through them. Glass reflectors, on the other hand, permit some of the light to pass through the reflectors which in turn is reflected from the light ceiling and walls.

(*i*) ADVANTAGES OF REFLECTORS.—Lamps without reflectors were debarred on account of the glare which resulted when a man looked up from his work. Furthermore, 62 per cent. more illumination was delivered on the working surfaces by lamps equipped with reflectors than by bare lamps of the same wattage. It was considered a good investment to provide lamps with the most efficient reflectors available.

296. Examples of Factory Tungsten Lighting Systems.*—These installations do not in general have drop lamps, the lamps overhead providing for nearly every requirement.

Feet and inches			Size[1] of lamp, watts	Watts per sq. ft.	Class of work and character of surroundings.[2] Opal or clear prismatic glass reflectors used
Ceiling or girder height	Mounting height above floor	Spacing distance			
8–1	7–6	8–0 × 8–0	60	0.94	Detail work—light ceiling, no walls.
9–0	8–6	8–0 × 8–6	100	1.47	Bench work, flat—no ceiling, dark walls.
11–1	10–3	8–0 × 8–9	100	1.43	Bench work—no ceiling, dark walls.
11–9	11–0	8–0 × 9–6	100	1.32	Machining—dark ceiling, no walls.
11–9	11–0	8–0 × 8–9	100	1.43	Machine work—dark ceiling and walls.
12–0	11–3	8–0 × 8–0	100	1.56	Machine work—dark ceiling, no walls.
12–0	11–3	8–0 × 8–0	100	1.78	Machine work—dark ceiling, no walls.
12–0	11–3	7–0 × 8–0	100	1.78	Bench work—dark ceiling, no walls.
12–6	12–0	8–0 × 10–0	100	1.25	Machine work—dark ceiling, no walls.
13–8	12–10	8–0 × 8–6	100	1.47	Machine work—dark ceiling and walls.
16–0	14–6	8–0 × 8–9	100	1.43	Detail work—no ceiling, dark walls.
16–0	15–2	8–0 × 10–0	100	1.25	Rough work—no ceiling, light walls.
16–0	15–2	11–6 × 16–0	250	1.36	Painting machines—no ceiling, light walls.
16–0	15–2	10–0 × 12–0	250	2.08	Fine die work—no ceiling, dark walls.
16–0	15–2	13–0 × 14–0	250	1.37	Bench work—no ceiling, dark walls.
24–9	21–3	10–0 × 12–0	250	2.08	Fine assembly work—dark ceiling, no walls.
24–9	21–3	10–0 × 12–0	250	2.08	Machine work—dark ceiling, no walls.
24–9	21–3	10–0 × 12–0	250	2.08	Testing—dark ceiling, no walls.
25–2	21–7	10–0 × 12–0	250	2.08	Testing—dark ceiling, no walls.

* FACTORY LIGHTING SYSTEMS, Clewell.

[1] These data are based on the earlier tungsten-lamp efficiencies. With the present (June, 1915) efficiencies, the new 40-, 60- and 200-watt lamps would give about the same illumination respectively as the old 60-, 100- and 250-watt lamps tabulated above, and the *watts per square foot*, consumptions shown would therefore be decreased accordingly—an average decrease in consumption of about 30 per cent.

[2] In factory construction, manufacturing spaces often occur where the girders and columns form the boundary lines without walls. Similarly open girder construction often occurs, where no ceiling exists.

297. Illumination Data on a Railway Shop Installation.*—

Location	Sq. ft. floor	Style and watts lamp	Total No. of lamps	Feet above floor	Watts per sq. ft.
Coach, shop office	396	Tungsten 60 watts	5	9	0.75
Coach, center bay	19,200	Arc 6.5 amp	11	36	0.41
Coach, side bays	81,600	Tungsten 250 watts	120	18	0.37
Coach, toilet room	1,760	Tungsten 60 watts	15	9	0.51
Main paint shop	**79,200**	**Tungsten 250 watts**	**124**	**18**	**0.39**
Paint shop office	870	Tungsten 60 watts	15	9	1.03
Paint, toilet room	1,890	Tungsten 60 watts	12	9	0.38
Wood mill offices	600	Tungsten 60 watts	8	9	0.80
Wood mill toilets	600	Tungsten 60 watts	4	9	0.40
Mill, first floor	**26,457**	**Tungsten 250 watts**	**64**	**16**	**0.60**
Mill, second floor	26,457	Tungsten 250 watts	64	15	0.61
Mill, tool room	600	Tungsten 60 watts	6	9	0.60
Wheel shop, total	9,050	Tungsten 250 watts	22	18	0.61
Main tank shop	36,540	Hewitt "P"	25	35	0.263
Tank offices, etc	2,350	Tungsten 60 watts	22	9	0.51

298. Draughting-room Lighting.—In the illumination of draughting rooms the requirements are:†

1. Good and sufficient light for each person.
2. Uniform distribution of light provided by lamps in such numbers and so arranged as to furnish illumination which is satisfactory without regard to the arrangement of tables.
3. An arrangement of lamps that will avoid glare and subsequent eye-strain.
4. A system which will furnish illumination on the drawing boards with a minimum of shadow effect when using instruments and ruling devices.
5. An intensity of illumination which will permit the discernment with ease of fine lines and detail, and which will be sufficiently penetrating for tracing work.

Increasing the number of direct-lighting units used increases the number of shadows, and reducing the number of lights increases the sharpness of the shadows. Semi-indirect or possibly indirect lighting furnishes probably the most satisfactory illumination.

Fig. 150 shows a layout that was adopted after exhaustive trials of many methods of draughting-room lighting with tungsten lamps. Four 40-watt lamps are used to each cluster

* Railway Electrical Engineer, June, 1912.
† C. E. Clewell, Electric Journal.

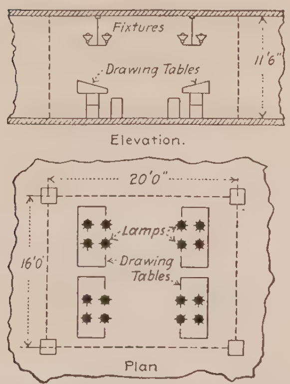


FIG. 150.—Satisfactory drafting-room lighting. 40-watt tungsten lamps with reflectors pointed upward.

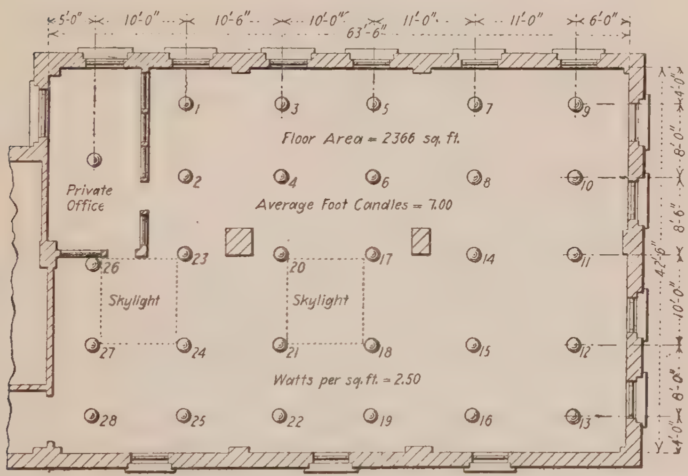


FIG. 150a.—Example of drafting-room lighting by the indirect system. (National X-ray Reflector Company.) Office of Roberts & Schaefer Co., McCormick Building, Chicago, Ill. At outlets Nos. 5, 6, 7, 8, 15, 17, 21, 26, 27 and 28, one (1) 150-watt tungsten lamp is used. At outlets 1, 2, 3, 4, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20, 22, 23, 24, and 25 one (1) 250-watt lamp is used. In general, 250-watt lamps are used where fine detail work is done and 150-watt lamps where less illumination is required. See sectional view in following illustration.

and four clusters to a bay. The lamps, supported in inverted translucent reflectors (Alba reflectors), direct most of the light

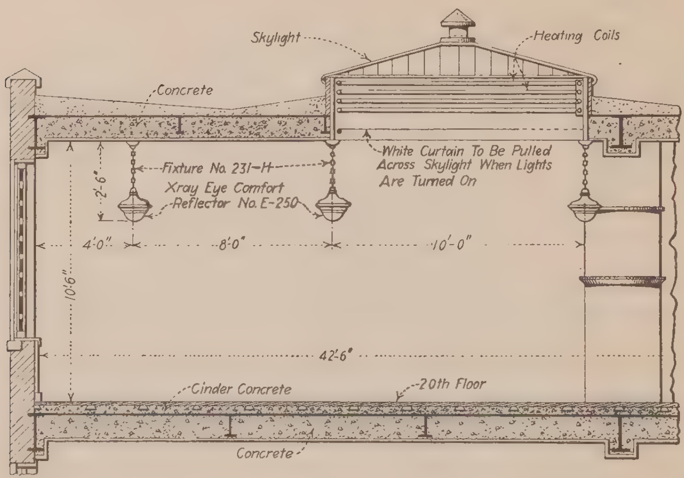


FIG. 151.—Sectional view of the drafting room, the plan-view of which is shown in Fig. 138.

to the ceiling, from which it is reflected to the work. It is semi-indirect or a combination of direct and indirect lighting. The feature of the above system that makes it worth while is that the light produced is practically free from shadows. Figs. 150A and 151 illustrate an example of a successful, indirect-lighting, draughting-room, installation. The Cooper-Hewitt system also gives excellent results in draughting-room lighting.

299. The Illumination Requirements of Banks, Insurance Offices, Etc.—For these applications the requirements are (in addition to those common to all store lighting, such as freedom from glare, uniformity, etc.) that the general lighting be soft and diffused and that the fixtures be in harmony with the general appointments of the rooms. At the same time, ample illumination must be provided at the tellers' windows and at the bookkeepers' desks. The general illumination is usually

supplied by indirect or semi-indirect units or bowl reflectors near the ceiling or by a generous number of simple and dignified chandeliers usually having but one light unit. The tellers' windows and desks are quite commonly lighted by some form of trough reflector running continuous around the inner side of the main screen cornice, and equipped with tungsten tube-type lamps. The switch control is usually so arranged that each cage may be lighted independently. It is usually much better if the general illumination over the bookkeepers' desks

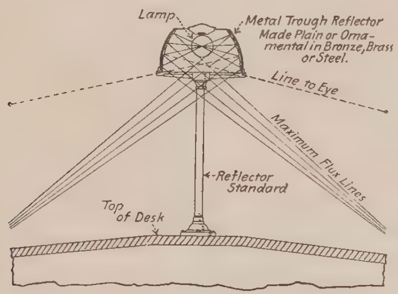


FIG. 152.—Bookkeepers' desk-lighting unit.

can be made of sufficient intensity and uniformity that all individual lighting can be eliminated. If this cannot be conveniently effected, a reflector arrangement similar to that shown in Fig. 152, extending the length of the desk, has been found very satisfactory for double desks and tables, protecting the eyes from the direct rays, while the long-distributed source of light prevents sharp reflection from the paper. For single desks or tables, a somewhat similar continuous reflector, arranged to throw the light in one direction only, is very satisfactory. This same arrangement is also quite suitable for public-library reading tables.

300. Moving-picture Theaters; Light Sources for Projecting Machines.—The same rules apply here as in any other theater for the general lighting of the auditorium, entrances, etc. The moving-picture machine requires an intense light,

from a source approximating a point source as nearly as possible. The crater of the positive carbon of an open arc is universally used. The direct-current arc is much more efficient than the alternating, about 25 to 30 amp. d.c. and 35 to 60 amp. a.c. being required for satisfactory illumination, although it is difficult to maintain a steady alternating arc at as high a very 60 amp. A rheostat must be used to decrease the voltage with direct current. But with alternating, a small auto-transformer, with variable-voltage secondary taps, and sufficient leakage in the magnetic circuit to supply the necessary ballasting effect, and obviate the use of additional resistance or reactance may be used. A choke coil with taps to vary the reactance in circuit is equally satisfactory from the operator's standpoint and is cheaper, but the power-factor is so low that few central stations will allow its use.

In addition to requiring much more power, the flicker of the alternating arc is objectionable for moving-picture work, though not noticeable in stereopticon pictures. Hence a small mercury rectifier is frequently used to supply direct current from an alternating source, the total amount of power required being less in spite of the losses in the rectifier. An auto-transformer with considerable magnetic leakage reduces the voltage to that required for the rectifier and supplies the necessary ballast effect. The current with one of these outfits is less than twice normal on dead short-circuit, such as is produced when starting the arc. The right-angle carbons give much the better results for steropticons, in which 10 to 15 amp. d.c. and 15 to 20 amp. a.c. will produce satisfactory illumination, but when the current exceeds 25 amp. this arrangement is not satisfactory on account of the magnetic blowout effect of the current. Hence for moving pictures the carbons are usually co-axial, and inclined at such an angle that the maximum light is given out along the axis of the lens system.

301. Church Lighting.—Probably in no other class of lighting have the principles of a scientific illumination been so generally abused. The requirements are: (1) that the minister and the choir may be seen plainly from any part of the

auditorium, without glare from any light source; (2) that the minister have ample light to read by, and the choir and organist have ample light by which to read music; and (3) that the congregation have ample general illumination to read from hymnals and prayer books. The first requirement was formerly almost universally violated. The general illumination was provided by fixtures, with poorly shaded lamps, which lung low and were so located that it was impossible for a large part of the congregation to look at the altar without having a light shining directly into their eyes. An hour of this is very tiring to even the strongest eyes. To prevent this, no church-lighting unit should throw light backward at a greater angle from the vertical than that at which the eyebrows will shade the eye—usually about 25 deg.

This can be accomplished in one of three ways or by a combination of the three: *First*, by using ordinary lamp units and reflectors, and concealing them behind pillars, ceiling beams or other members of the church architecture—possible only in certain cases. *Second*, by using an indirect or semi-indirect lighting system. In this case a certain amount of light is reflected into the eyes, but it is so well diffused, at such a sharp angle, and the light sources are of such low an intrinsic brilliancy as to be unobjectionable. *Third*, by using direct lighting with deep-bowl reflectors, or completely enclosing reflector globes, which completely, or nearly shade the eyes from light at a greater angle than 25 deg. The lights for the choir and minister can usually be concealed behind the chancel arch, or in some other suitable manner.

302. Hospital Lighting equipment must be so constructed that it can be kept clean with a minimum of time. The fixtures are frequently finished in white enamel to correspond with the other appliances in the institution.

303. For Lighting the Wards ordinary bracket fixtures are sometimes used, but indirect or semi-indirect lighting systems are probably preferable because the eyes of the patients, which may be in very weak condition, are thereby protected from glare. A semi-indirect lighting fixture (somewhat similar to that of Fig. 75) manufactured especially for ward illumination,

is constructed as follows: The spun brass bowl is white or green enameled on the outside. A silvered, ripple-glass reflector on the inside distributes the light over a wide angle on the ceiling. A thin blown-glass cover is provided to prevent the entrance of dust and, by using a proper shade of glass for it the diffuse light resulting will be practically as white as daylight. The fixtures can be furnished arranged for three, four, five or six lamps and with an electrolier switch practically any desired illumination intensity can be secured.

304. Bed Lights for Hospital Illumination are shown in Figs. 153 and 154. These can be used for examinations or by

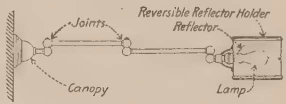


FIG. 153.—Hospital bed light.

the occupant of the bed. That shown is adjustable in any required direction. It has a reversible glass reflector polished on

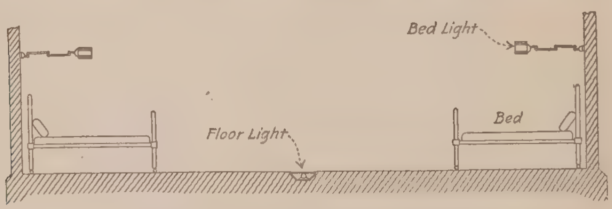


FIG. 154.—Hospital ward illumination.

one side so that it can be used as a concentrating reflector for examination or as an indirect fixture for general illumination.

305. Operating-table Reflectors for Hospitals should provide a strong light on the subject and should radiate minimum heat so that the surgeon will not be inconvenienced. Fig. 155 shows one design. The exterior finish is white enamel. It is arranged for six 100-watt lamps. Silvered ripple glass directs the light downward, producing an intensity of 43 ft.-c. on the working plane. The heat directed downward would be excessive unless carried away. The ventilating

feature consists of two tubes or flues which, when heated by the operation of the lamps, create a partial vacuum which draws in cool air between two glass plates and forces the heated air up and out. The lower plate is solid and set in a sliding frame.

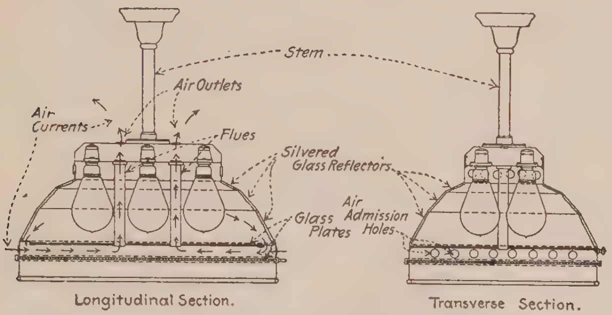


Fig. 155.—Ventilated operating-table reflector. (I. P. Frink Co.)

The upper plate, 2 in. above the lower one, is so mounted as to provide free air spaces at the sides, and at its center the two flues pass through. The resulting constant circulation maintains a bank of cool air above the head of the surgeon. Reflectors similar to that above described, but adjustable by

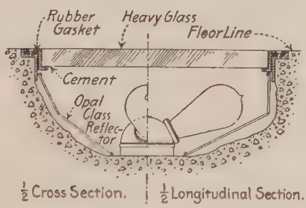


Fig. 156.—Hospital floor light as manufactured by the I. P. Frink Company.

hand as to height, can be purchased. In wiring the reflectors, half of the lamps should be served by one branch circuit and the other half by another to insure against darkness.

306. Floor Lights Are Sometimes Used for Night Lights in ward rooms. Fig. 156 shows a detail and Fig. 154 the application. The floor lights are installed about 25 ft. apart in large wards or one is used in a small ward and the 60- or 100-watt lamps

are wired on two or three circuits. The arrangement provides enough light for general illumination for night inspection.

307. Billiard-table Lighting.—At least two and preferably four light units with shaded or bowl-type reflectors located 3 to 4 ft. above the table should ordinarily be used over each table. Five or six units per table are still better, as accurate sighting necessitates the elimination of shadows. The units should be below the level of the eye and shaded to eliminate glare. Six 15-watt, four 25-watt or two 40-watt tungsten lamps with suitable reflectors will give brilliant illumination.

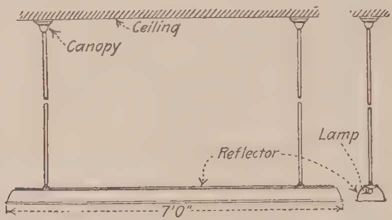


FIG. 157.—Special billiard-table fixture.

The reflectors and lamp spacing should be such that the illumination on the table will be uniform. One lamp about a foot inside each corner with one over the center provides one good arrangement. A special billiard-table reflector which may be used is shown in Fig. 157. This fixture utilizes four 35-watt tubular tungsten lamps, and should be hung approximately 3 ft. above the top of the table. The illumination over a standard billiard table lighted with this reflector is uniform from cushion to cushion. Chains may be used instead of rods for supports, which permits the fixture being pushed to one side to facilitate the making of massé shots, etc.

308. Cove Lighting is one form of indirect illumination. Fig. 158 illustrates the principles. The light sources are concealed in a cove near the ceiling and the trough-shaped reflector in which they are mounted directs the light from them to the ceiling from which it is reflected down into the room. Ceilings for such installations must be light in color so that they will reflect well. Because the light is reflected, more power is required to light a room to a given intensity by this method than

when direct lighting is used. However, since the light sources are entirely concealed and glare thereby eliminated, a lesser intensity of illumination will give satisfactory results than where the sources are visible. The light emanates from the ceiling and there are no shadows. The strain on the eyes is much less than with direct methods of illumination. In smoky communities, cove lighting is sometimes unsatisfactory because the ceilings and reflectors are rapidly darkened by the

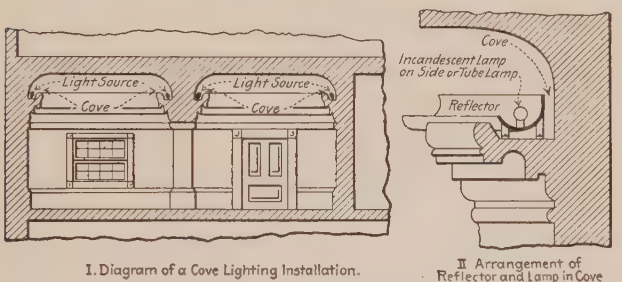


Fig. 158.—Cove lighting.

dirt and thereby rendered inefficient. A few bracket lamps or clusters on columns with their light sources concealed by translucent shades can be effectively used in cove-lighting installations to produce a few shadows and to remove the cold, dead effect which is noticeable where no light sources are visible.

309. Some Examples and Data on Cove-lighting Systems are as follows: In the ladies' parlor of the Hotel Jefferson, St. Louis, a cove-lighting arrangement is in operation which requires sixty-five 60-watt lamps. The room is oval in plan, 34 ft. 8 in. long by 26 ft. 6 in. wide, giving a floor area of 645 sq. ft.* On the basis of 60-watt lamps the power consumption is about 6.0 watts per sq. ft. as against about 2.5 watts per sq. ft. which would ordinarily be ample for a room of this character with direct illumination.

Cove lighting, supplemented by candelabras on columns, is

* Cravath and Lansingle, Practical Illumination.

used in the palm room of the Bellevue-Stratford Hotel, Philadelphia.* The specific power consumption is 3 watts per sq. ft. To obtain these results, 520, 25-watt tubular tungsten lamps were used in 520 ft. of specially designed cove reflector. The illumination at the table top level varies from a maximum of 2.6 ft.-c. in the center of the room to a minimum of 1.6 ft.-c. in the corners. The ceiling is cream white and frescoed in bright colors. Side walls are terra-cotta buff.

* H. W. Johns-Mansville Co., ILLUMINATION DATA.

SECTION 9

EXTERIOR ILLUMINATION

310. General Requirements for Street Lighting.—In all classes of street lighting (see Art. 312) it is desirable to have uniform intensity, good diffusion to prevent sharp shadows, and low intrinsic brilliancy to reduce glare. It is not usually feasible to attain all of these desirable conditions.

311. The Lighting of Streets is Desired to Promote the Facility of the Following Activities:* The pedestrian should be able to distinguish inequalities and obstructions in the footway and other pedestrians and vehicles. He should be able to distinguish the numbers on houses, although this is frequently impossible because of the poor locations of such numbers. He should be able to read at points not greatly distant from each other, ordinary memoranda such as addresses, and to note clearly the actions of marauders.

The driver of a vehicle has much the same needs as the pedestrian, except that the traffic stream of which he is a part is rapidly moving and it is therefore necessary that the roadway appear more clearly and that the intent of other drivers be evident at a considerable distance. The effects of glare are most harmful in the case of motorists.

The police require a degree of illumination which will permit the recognition of people and which will assist them in distinguishing between fixed objects and men trying to conceal themselves. It has been suggested that there should be sufficient illumination to permit the police to note automobile license numbers, but with the wide variety of license plates and the latitude allowed in some places in methods of attaching them to cars, it frequently occurs that this is not feasible.

* Report of Committee on Street Lighting, National Electric Light Association Convention, Chicago, May, 1916.

312. Desirable Illumination Densities for Streets and a Classification of Streets as Regards Their Illumination Requirements.*—Illumination density (foot-candles) is usually adjusted with reference to traffic density and real estate development. Departures from these general practices are noted in the case of display lighting for advertising purposes based upon the principle that "trade follows the light." In general, with increasing efficiency of illuminants densities are being increased. The following are representative of good modern practice in streets of the several classes described:

Classification letter	Class of street	Average illumination density in foot-candles (that is, in lumens per square foot)	Desirable characteristic
A............	Important avenues and heavy traffic streets.	0.5 to 1.0	Ample light on building fronts.
B............	Secondary business streets.	0.1 to 0.2	Ample light on buildings.
C............	City residence streets.	0.05 to 0.10	Subdued light on building fronts.
D............	Suburban highways.	0.01 to 0.02	Maximum light on roadway.
E............	Suburban residence streets.	0.005 to 0.015	Very subdued light on building fronts.

NOTE.—In addition to these there may be a "white way" where 1.5 or even 2.00 ft.-c., in addition to the illumination produced by the window and sign lights, is permissible.

313. Electric-light Sources Available for Street Lighting.—Arc lamps and gas-filled tungsten incandescent lamps provide the most economical illumination for streets. Of the arc lamps, the open and enclosed carbon arcs have become practically obsolete as street illuminants. The metallic-flame arc (Art. 189) has largely replaced the older forms of lamps. The color of the light is white and the distribution curve shows a maximum candle-power from 15 to 25 deg. below the hori-

* REPORT OF COMMITTEE ON STREET LIGHTING, National Electric Light Association Convention, Chicago, May, 1916.

zontal. Its maintenance cost is comparatively low. The efficiency of light production varies from 0.4 to 0.5 watt per mean lower hemispherical candle-power.

The flame carbon lamp is (Art. 190) the most recent arc-lighting development. The efficiency of light production varies from 0.25 to 0.35 watt per mean lower hemispherical candle-power. The light-distribution curve shows a maximum candle-power from 20 to 30 deg. below the horizontal. The maximum candle-power varies from 1,600 to 2,500, depending upon the carbons used.

Tungsten series incandescent lamps (Art. 165) are available in sizes ranging from 60 to 1,000 apparent c.p. The efficiency of light production varies approximately from 0.8 to 0.45 watt per candle. When properly equipped with a suitable reflector (Art. 330), they are well suited for street illumination. The light flux from tungsten lamps may be directed in almost any desirable direction.

314. Number and Size of Units for Street Lighting.*—Using a small number of units of very high candle-power, mounted at considerable height and placed at great distances, requires a larger total light flux to secure the minimum allowable illumination midway between units than is required with closer spacing. There is some waste of energy where the sources are spaced at great distances from one another. On the other hand, increasing the number of units increases the installation and maintenance cost of the system. In general, if energy cost is low, large units at great distances apart are better; if energy cost is high, small units placed at frequent intervals are more economical.

On streets having trees, arc lamps cannot, even if their use does for some reason or other appear desirable, be used because the height at which they should be mounted will cause the trees to throw dense shadows on the streets. In such cases tungsten lighting is always most suitable. In making calculations of illumination density on the street surface, the point-by-point method should be used, making calculations quarter and halfway between units, under each unit, and about 25 ft.

* C. E. Stephens.

from each unit. In making these calculations it is necessary to consider only the illumination due to the two nearest units.

315. In Residence-street Lighting the Use of Relatively Small Units is Usually Preferable* because with the smaller units the illumination is more uniform. Another feature that should be considered in this connection is that although large units are, for a given installation, preferable from the standpoint of installation and maintenance costs because a minimum number of units is necessary, considerable of the light from these large units will be wasted in lighting the yards facing

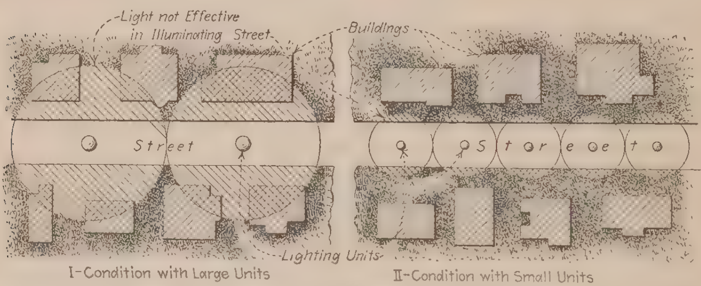


FIG. 159.—Illustrating how a considerable portion of light is ineffective in illuminating a street where high-power lighting units are used.

the street. With small units spaced closer together, most of the light falls on the street and walks and little is wasted (Fig. 159).

316. Distribution of Street Illumination.†—In the illumination of a sidewalk, for example, the required minimum being 0.04 ft.-c., the specification could be better fitted by common candles placed 6 ft. high and 6 ft. apart along the curb than by powerful sources of light spaced 200 ft. apart, although the latter would give more than 50 times the total light of the former. See Fig. 159. Some point between these extremes should evidently be chosen in the joint interest of economy and good average illumination, and a few trial computations will bring out the facts. In general, radiants of moderate power placed at moderate distances give the best illuminating effects, whether on the street or indoors.

* C. E. Stephens.

† Bell, STANDARD HANDBOOK.

317. Time for Turning Street Lights On and Off.—Street lamps should be turned on not later than 30 min. after sunset, and should be turned off not earlier than 30 min. before sunrise (based on local, not standard, time). In clear weather and around full moon, moonlight is sometimes considered to give sufficient illumination for Class *D* and *E* streets. See Art. 312. The practice of turning out street lighting units on moonlight nights is not followed except in small towns, and the practice, all things considered, has little or nothing to commend it.

318. Spacing and Height of Units.*—The uniformity of illumination with a given unit varies with the distance between units and their height. The very nature of the street area determines that the light units must be in a single or double row along the street. The number and size of units and their height are determined by the intensity requirements and cost of operation. In making a selection of units for a given condition it is necessary, therefore, to carefully consider the curve of light distribution of the available units. Increasing the height of the lamp decreases the intensity of illumination directly under the lamp quite rapidly and does not materially change the intensity at greater distances from the lamp. The height of a lamp is usually limited on account of the extremely high cost of installation, maintenance, tree obstruction, etc.

319. Where Lamps are Installed on Streets Bordered with Trees the lamps should always be hung a trifle lower than the lower branches of the trees. If they are not, heavy shadows will be cast by the branches and the effectiveness of the illumination will be greatly impaired.

320. In Locating Lamps for Outside Illumination one should be placed where possible at each street intersection so that the light will be useful in all four directions. Spacing distances between street intersection lamps is a thing that must be determined by local conditions. Where blocks are long, or strong illumination is required for display purposes, one, two or even more lamps can be equidistantly located between the street intersection lamps.

* C. E. Stephens.

321. In Locating Lamps along Curved Roadways it is often considered preferable to place them as suggested in Fig. 160 rather than all on the same side of the road. When arranged as shown, more lamps can be seen at one time and it is claimed that distant moving objects in the road are more effectively revealed in that they will always lie between the observer and the lights.

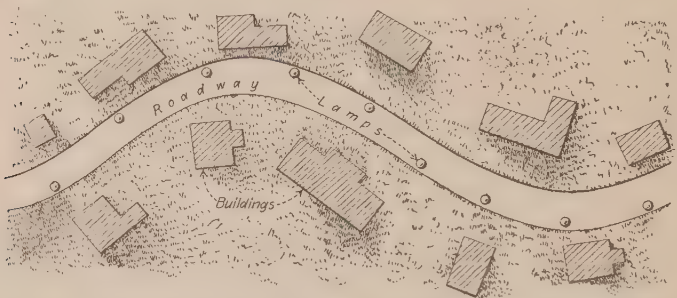


FIG. 160.—Preferable method of locating lighting units along a curved roadway.

322. Height of Arc Lamps for Outdoor Illumination.—Generally speaking the lamps should be hung as high as feasible. As a rule, arc lamps are hung too low for best results. From 35 to 45 ft. from the ground is probably about right for average conditions, but it is seldom feasible to place lamps this high because of practical considerations.

323. Arrangements of Series Tungsten Street-lighting Units.*—The following arrangements (see Fig. 161) are commonly employed in installing street lighting units:

1. *The Parallel Arrangement.*—This exists when units on the two sides of the street are located directly opposite each other.

2. *The Staggered Arrangement.*—This exists when units on the two sides of the street are located alternately, instead of being located opposite each other.

3. *The Single-line Arrangement.*—This exists when units are placed in a single line, either in the center, or along one side of the street.

* National Electric Lamp Association.

4. *The Arch Arrangement.*—This exists when units are suspended in the form of an arch across the street from a messenger cable or arch structure.

324. Arrangement of Series Tungsten Lamp for Different Services* (Fig. 161).—For business sections, either the parallel or staggered arrangement is usually adopted, in order to ob-

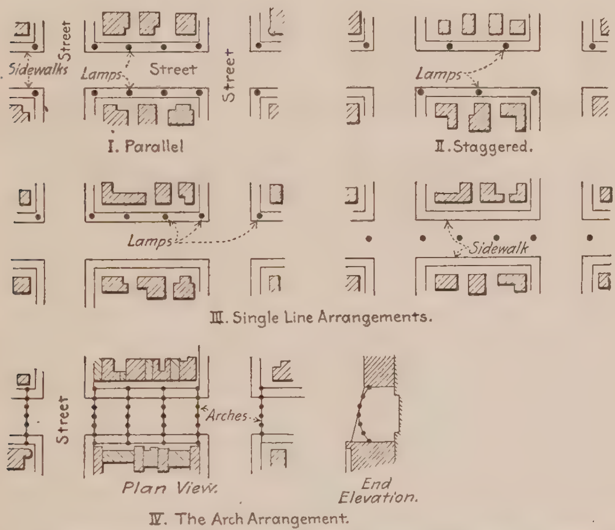


FIG. 161.—Arrangement employed in locating tungsten series street lighting units.

tain a symmetrical and artistic appearance. Ornamental standards placed at short intervals are frequently used. This practice affords a brilliant street illumination, and, moreover, enables show-window displays to be seen after the interior lighting has been turned off for the night. The arch arrangement, frequently termed a system of "display lighting," is being employed with considerable success in business districts. With this system, however, uniformity of distribution must usually be sacrificed for attractive appearance. In lighting residence streets, suburban streets, parks and driveways, the staggered system of single light units is usually preferable.

* National Electric Lamp Association.

This system tends to give a relatively even distribution of light with minimum installation cost.

325. Tungsten Cluster Street Lighting.—Very artistic and attractive effects can be secured by using clusters of tungsten lamps in opal or other diffusing globes, surmounting ornamental poles. This system is often used for boulevard, business street and park lighting.

326. In Locating Single Light Series Tungsten Units, along the Curb (see Fig. 161), the best results are obtained by allowing the lamps to hang from 1 to 1½ ft. outside of the curb line. In the case of single-line lighting, a distance of from 3 to 5 ft. outside of the curb line is usually desirable. Lighting units may also be placed over the center of the street, either by suspension similar to that commonly employed for arc lamps, or on ornamental standards placed on "Islands of Safety."

327. Desirable Mounting Heights for Tungsten Street Series Lamps.*—In general, a height of from 12 to 16 ft. is desirable for single light units ranging from 25 to 80 c.p. This height is advisable from the fact that in the majority of smaller and in some of the larger towns or cities, the streets are heavily wooded, and it is necessary to place the illuminants beneath this natural canopy of foliage. In the case of higher candle-powers as, for example, the 200-c.p. tungsten lamp, a height of 20 to 25 ft. may be maintained unless the lamp is enclosed in a diffusing globe, in which case the above-mentioned height of from 12 to 16 ft. would hold. When ornamental standards with two or more lights are used, a height slightly greater than 12 ft. but not exceeding 16 ft. may effectively be employed. The height of lamps above the street, rather than the candle-power, determines the maximum spacing of units. When lamps are placed low and at exceptionally long intervals, an object in the roadway or unevenness of the pavement is greatly exaggerated and distorted. An increase in candle-power merely deepens the shadows and increases the distortion.

328. When Any Lamp is Hung so Low That It Lies Within the Range of Vision of a nearby observer the glare from the

* National Electric Lamp Association.

unit should be eliminated by the application of a proper reflector or shade.

329. A Reflector Should Always Be Used with Any Incandescent Street-lighting Lamp.—Where no reflector is used a large portion of the light generated is projected above the lamp into the air and is wholly ineffective in lighting the street.

330. Reflectors for Street Series Tungsten Lamps.—With single light units it is essential to employ some type of reflector,

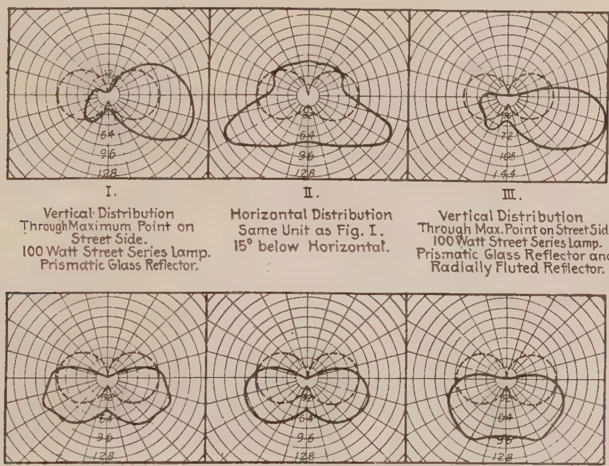


FIG. 162.—Distribution curves for typical reflectors for use with series tungsten lamps.

so that the light emitted above the horizontal shall be reflected on to the street. There are five general forms of reflectors used with tungsten street series lamps. Typical distribution curves for reflectors of these different types are shown in Fig. 162.

1. A reflector which is of "prismatic glass" so designed as to throw the maximum amount of light up and down the street at an angle of about 22½ deg. with the curb line (Fig. 163, *I*).

2. A combination unit formed by using a "radially fluted"

reflector in connection with the "prismatic glass" reflector (Fig. 163, *II*).

3. A metal reflector which consists of a "radially fluted" disc varying from 18 to 22 in. in diameter, the under surface of which is finished in heavy enamel (Fig. 163, *III*).

4. A metal reflector which resembles an inverted cone (diameter 18 to 22 in.), having its under surface white enameled.

5. A flat metal reflector varying from 12 to 16 in. in diameter and having its under surface white enameled or painted.

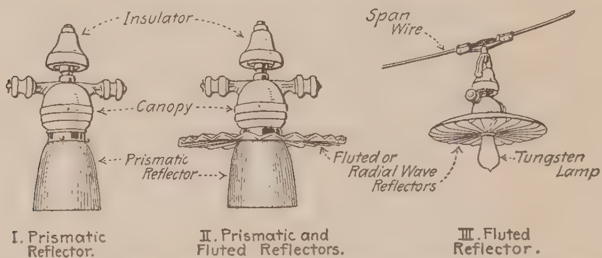


FIG. 163.—Reflectors for tungsten series street lighting lamps.

331. Series Tungsten Street Lighting.—The Adjuster Socket System operates only on constant-potential circuits. It consists of a simple series of lamps connected across high-tension constant-potential alternating-current mains, or across the secondary terminals of a constant-potential transformer or auto-transformer. A reactance coil is connected in shunt across the terminals of each lamp. When the lamp is burning the reactance coil takes only 4 or 5 per cent. of the current. If the lamp filament is broken or the lamp removed, the voltage, forces the total current of the circuit through the reactance coil, magnetizing it to saturation, whereupon it produces a counter-electromotive force equal to the potential difference across the lamp when burning. This maintains the continuity of the circuit at all times.

332. Fixtures for Street Tungstens.—Fig. 164 shows two of the most popular tungsten street-lighting fixtures. That of *II* is arranged for fastening to a pole, while that of *I*, when in service, hangs from a cable or span wire supported by two poles.

333. Series Tungsten Street Lighting.—In the Regulator System the series of lamps is supplied from a constant-current regulating transformer (see section on *Transformers* in the author's American Electricians' Handbook). This automatically controls the current and voltage of the circuit, and maintains a constant current regardless of the number of lamps burning. A film cutout device, consisting of a receptacle

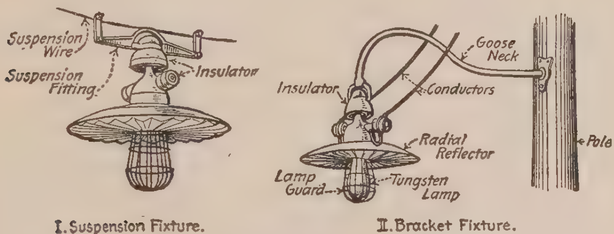


Fig. 164.—Street fixtures for tungsten lamps.

and socket located in the street hood, short-circuits the lamp and thus maintains the continuity of the circuit when a lamp burns out. The lamp cutout, used in the regulator system for maintaining the continuity of the circuit, consists of a thin copper, aluminum or lead disc coated with an insulating enamel, placed between clips provided in the socket. If the lamp burns out, the increase of potential across the clips punctures the film between the socket clips and short-circuits the lamp.

334. Series Tungsten Lamps May Be Operated on Arc Circuits to fill in between arc lamps, and hence they have been standardized at the normal arc-lamp currents, 3.5, 4.0, 5.5, 6.6 and 7.5 amp. (see the table of *Series Tungsten Lamp Ratings and Characteristics* in the author's American Electricians' Handbook). Some lower-amperage lamps have been used in the past, but are no longer standard. The 4.0- and 6.6-amp. lamps are in most general use and when a new series tungsten system is to be installed, lamps of either one or the other of these "amperages" should be selected. The 4.0-amp. lamp has the advantage of lower line loss for the same size conductor and is, therefore, preferable, other considerations being equal.

335. Ratings of Series Tungsten Lamps for Street Lighting.—Street lighting contracts are usually and should be based on the candle-power of the light source. Tungsten street series lamps are, therefore, rated in mean horizontal candle-power and current, and not in total watts and volts as are the multiple lamps.

336. Freight-yard Lighting.—Tests made by the Missouri Pacific Railway System* indicate that flame arc lamps are more satisfactory than any other illuminant on account of the greater penetration of the yellow light through fog and smoke. It was found that the numbers on a freight car could be read at a distance of 100 to 175 ft. from the flame arc lamp, this being a very important feature in a classification yard. Regenerative arc lamps spaced on an average 400 ft. apart, gave very satisfactory service in the Missouri Pacific yards at Dupo, Ill. They were located 40 ft. above the rails so that men standing on the cars could see under the lamps.

337. Outdoor Hippodromes, Ball Parks, Etc.—For this type of lighting, big search lights, throwing a very distributed ray may be used. At the Cincinnati National League Ball Park, six search lights, mounted on three high towers, furnishing illumination for the diamond and outfield, and four others mounted on the roof of the grandstand to illuminate the upper air, in order that flies might be seen gave quite satisfactory service, although no national league games have been played at night. A similar arrangement was tried out in Chicago. These lights took 150 amp. each at 110 volts. In Pittsburgh five search lights mounted on the grandstand, at Forbes Field, have furnished illumination for a regular evening outdoor hippodrome performance for several years.

338. Sign Lighting.—The object of an electric sign is to attract attention to itself. Even in this case, however, the rule holds that the lights themselves should not be noticeable. That is, when looking at a sign, we should not see the individual light sources, as units, but only the letters or outline of the sign, and a sign in which the lamp units are prominent gives a repulsive effect. To make a sign readily legible, the letters

* ELECTRICAL WORLD, April 6, 1911.

should be rather large, with generous spacing between them, and should be white, with a black or dark blue background, that they may have a good appearance by daylight as well as by night. Raised letters stand out prominently by day and night and are very effective for many purposes. Flat surface

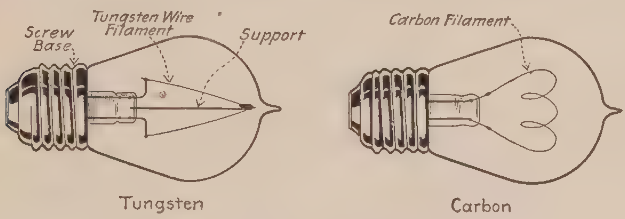


FIG. 165.—Sign lamps.

letters are very legible, are easily washed, and are to a certain extent self-cleaning. Grooved letters require fewer lamps per letter, and are very efficient when viewed from within a rather restricted angle, as the sides of the groove or trough reflect most of the light which is otherwise wasted. These signs are less spotty than any other type.

339. The Light Distribution of Sign Lamps (Fig. 165) is such that most of the light is given off at the sides and little from the end, as shown in Fig. 166 so that with a properly designed sign letter it is very easy to cause the individual lamp to be so merged into the general effect as to be unnoticed.

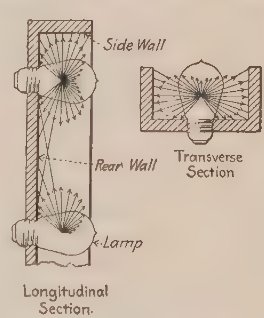


FIG. 166.—Illumination of rear and side walls of a letter for an electric sign.

340. Provision Should Be Made for Cleaning All Signs Regularly, as dirt reduces the legibility and brilliancy, gives them a slovenly and neglected appearance, and robs them of much of their advertising value.

341. Incandescent Sign Lamps (see Fig. 165) are usually of low wattage, 5, 10 and 20 watts being standard ratings. Tungsten-filament lamps have almost entirely superseded those of other types for sign work because of their high effi-

ciency. See also the data on sign wiring in the *Wiring Section* of the author's AMERICAN ELECTRICIAN'S HANDBOOK.

342. Sign Flashers.—A moving sign is frequently much more effective than one in which all the lamps burn continuously, and requires much less current. In general a saving of 30 to 50 per cent. in energy is affected, depending on the number of lamps in operation at one time. See the section *Interior Wiring* in the author's AMERICAN ELECTRICIANS' HANDBOOK for further information.

343. The Most Desirable Colors for Sign Lamps Are opal and yellow on account of their low absorption factors. Ruby is also much used as red light and is distinguishable at great distances. Green, blue and purple are not efficient for many practical purposes and are not to be generally recommended. The percentage of light absorbed by lamps of different colors is given in Table 344, taken from data published by the *National Electric Lamp Association.* A larger absorption factor, in general, is accompanied by a higher heating effect and a shorter life. Lamps of warm, contrasting colors give pleasing effects. In general, a solid mass or continual line of color is more attractive than a mixture of colors, as the introduction of different colors breaks the continuity of outline and thus detracts from the effect.

344. Absorption Factors of Colored Sign Lamps.—

Superficial colors		Natural colors	
Designation	Per cent. loss of light compared to clear bulb	Designation	Per cent. loss of light compared to clear bulb
Yellow	7	Opal	11.0
Opal	13	Amber or canary	21.0
Dull-finish yellow	21	Pink	29.0
Amber	25	Green	77.0
Dull-finish pink	36	Ruby	84.0
Dull-finish orange	44	Purple	93.0
Ruby	81	Blue	97.5
Green	94		
Blue	96		
Purple	96		

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